12

BEWCASTLE

554.2

6718406

NATURAL ENVIRONMENT RESEARCH COUNCIL

GEOLOGICAL SURVEY OF GREAT BRITAIN

GEOLOGY
OF THE COUNTRY
AROUND
BEWCASTLE

1970

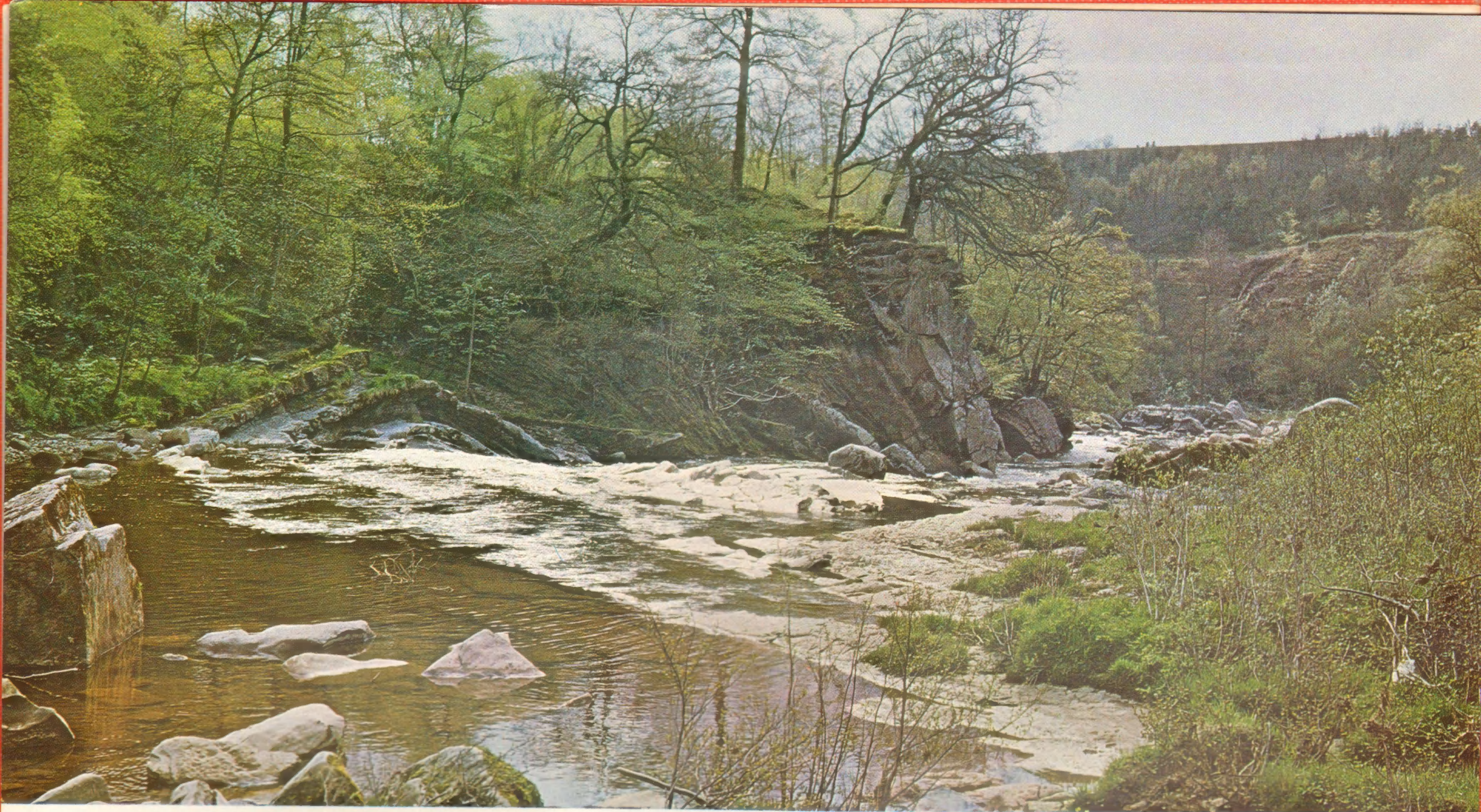
UNIVERSITY
LIBRARY
DURHAM

WITHDRAWN
UNIV
DUNELM
FROM STOCK

WITHDRAWN

WITHDRAWN + FROM STOCK +
UNIV DUNELM

PLATE I (*Frontispiece*)



Anticline in the Penton Limestone at Penton Linns, from the Scottish bank

NATURAL ENVIRONMENT RESEARCH COUNCIL
INSTITUTE OF GEOLOGICAL SCIENCES

MEMOIRS OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN
ENGLAND AND WALES

Geology of the Country around BEWCASTLE

(*Explanation of One-inch Geological Sheet 12, New Series*)

BY
J. B. W. DAY, B.SC.

with contributions by
D. H. Land, B.Sc., R. H. Price, B.Sc., and D. A. C. Mills, B.Sc.

Palaeontology by
W. H. C. Ramsbottom, M.A., Ph.D., and F. W. Anderson, D.Sc., F.R.S.E.

Petrography by
R. K. Harrison, M.Sc.

[illegible] UNIVERSITY
SCIENCE
- 5 OCT 1970
SECTION
LIBRARY

LONDON
HER MAJESTY'S STATIONERY OFFICE
1970

The Institute of Geological Sciences
was formed by the
incorporation of the Geological Survey of Great Britain
and the Museum of Practical Geology
with Overseas Geological Surveys
and is a constituent body of the Natural Environment Research Council

© Crown copyright 1970

554.2
MEM
(12)

SBN 11 880075 2*

Printed in England for Her Majesty's Stationery Office
by Eyre & Spottiswoode Limited at Grosvenor Press, Portsmouth

S51916

PREFACE

THE COUNTRY around Bewcastle was originally surveyed on the six-inch to one mile scale by J. C. Ward, D. Burns and J. G. Goodchild under the superintendence of W. T. Aveline and H. H. Howell between the years 1875 and 1878. It was revised by H. Miller Jnr. and C. T. Clough between 1881 and 1884 and published, hand coloured, on the one-inch scale on Old Series Sheet 106 NW in 1889. Triassic and igneous rocks were picked out on this map, but the Carboniferous strata forming most of the district were shown as undifferentiated Carboniferous Limestone Series. No explanatory memoir for the sheet was published.

A strip of ground within the southern margin of the district was remapped by Dr. F. M. Trotter and Mr. T. Eastwood between 1921 and 1927 in order to round off work on the Brampton (18) district and details of the geology of the strip were included in the corresponding memoir published in 1932. However, the bulk of the present revision, supervised by Mr. W. Anderson, was carried out during the years 1952–8 by Messrs J. B. W. Day and R. H. Price in central and north-western parts of the district respectively, and by Messrs. D. H. Land and D. A. C. Mills in the north-eastern part. The list of six-inch maps with the names of the surveyors is given on p. xi.

Mr. Price resigned in 1957 in order to take up an appointment as Divisional Geologist to the National Coal Board and in consequence the task of compiling this memoir has fallen mainly to Mr. Day. Messrs. Land and Mills have made contributions to some of the stratigraphical and structural chapters. Algal floras and their environments have been discussed by Dr. F. W. Anderson and Lower Carboniferous ostracods have been determined by Dr. J. E. Robinson of University College London. An account of the Upper Border Group miospores has been contributed by Dr. R. Neves of Sheffield University. Dr. W. H. C. Ramsbottom, assisted by Mr. W. G. E. Graham, has been responsible for all the work on Carboniferous macrofaunas except for those pertaining to the Coal Measures, which have been identified by Mr. M. A. Calver. Representative specimens of igneous rocks have been described by Mr. R. K. Harrison, who has also written a chapter on the petrography of some of the Lower Carboniferous sandstones. The memoir has been edited by Messrs. E. H. Francis and B. J. Taylor.

K. C. DUNHAM
Director

Institute of Geological Sciences
Exhibition Road
South Kensington
London, S.W.1
29th October 1969

CONTENTS

(References are listed at the end of each chapter)

PAGE

PREFACE BY THE DIRECTOR iii
LIST OF ILLUSTRATIONS vii
EXPLANATION OF PLATES ix
LIST OF SIX-INCH MAPS xi
CHAPTER I. INTRODUCTION 1
Area and physical features, 1. Previous Research, 3. Geological Sequence, 3. Geological History, 5.
CHAPTER II. CARBONIFEROUS CLASSIFICATION AND PALAEOGEOGRAPHY 8
Classification, 8. Palaeogeography, 11.
CHAPTER III. LOWER BORDER GROUP 15
General Account, 15. Lynebank Beds, 17. Bewcastle Beds, 25. Main Algal Beds, 43. Cambeck Beds, 66.
CHAPTER IV. MIDDLE BORDER GROUP 82
General Account, 82. Details, 84.
CHAPTER V. UPPER BORDER GROUP 105
General Account, 105. Details, 110.
CHAPTER VI. LIDDESDALE GROUP 156
General Account, 156. Details of Lower Liddesdale Group, 159. Details of Upper Liddesdale Group, 161.
CHAPTER VII. LOWER CARBONIFEROUS PALAEONTOLOGY 166
Faunas, 166. Upper Border Group miospores, 172. Algae, 175. Sequence of algal limestones, 179. Fossil Lists, 191. Selected localities of fossils, 199.
CHAPTER VIII. PETROGRAPHY OF LOWER CARBONIFEROUS SANDSTONES 208
General Account, 208. Details, 211.
CHAPTER IX. MILLSTONE GRIT SERIES 222
General Account, 222. Details, 224.
CHAPTER X. COAL MEASURES 226
General Account, 226. Details, 227.
CHAPTER XI. PERMO-TRIASSIC ROCKS 229
General Account, 229. Details, 230.
CHAPTER XII. STRUCTURE 232
General Account, 232. Details, 235.
CHAPTER XIII. IGNEOUS ROCKS 242
General Account, 242. Details, 242.
CHAPTER XIV. GLACIAL DEPOSITS 251
General Account, 251. Details, 252.
CHAPTER XV. RIVER DEVELOPMENT AND RECENT DEPOSITS .. 258
River Development, 258. Alluvium and river terraces, 261. Peat, 262.
CHAPTER XVI. MINERAL PRODUCTS AND WATER SUPPLY 264
Coal, 264. Gypsum and Anhydrite, 266. Building Stone, 266. Sand and Gravel, 267. Road Metal, 267. Peat, 267. Water Supply, 268.
APPENDIX I. SECTIONS MEASURED AT OUTCROP 270
APPENDIX II. RECORDS OF BOREHOLE SECTIONS 324
APPENDIX III. LIST OF GEOLOGICAL SURVEY PHOTOGRAPHS.. .. 339
INDEX 343

ILLUSTRATIONS

TEXT FIGURES

PAGE

FIG. 1. Sketch-map showing the location of the Bewcastle district (Sheet 12) 1
FIG. 2. Principal streams and rivers of the district and the catchment areas to which reference is made in the 'details' sections of the stratigraphical chapters 2
FIG. 3. Sketch-map showing the distribution of the principal geological formations in the district 5
FIG. 4. Sketch-map showing the distribution of Lower Border Group strata east of the Hole of Lyne Fault .. .. *Facing* 16
FIG. 5. Generalized vertical section of the Lynebank Beds 19
FIG. 6. Comparative vertical sections of the Lynebank Beds 21
FIG. 7. Generalized vertical section of the Bewcastle Beds 27
FIG. 8. Comparative vertical sections of the Bewcastle Beds 29
FIG. 9. Sketch-map of the Bewcastle Beds in Ashy Cleugh .. .. *Facing* 38
FIG. 10. Sketch-map of the Bewcastle Beds in the Rigghead–High Grains area .. .. *Facing* 40
FIG. 11. Comparative vertical sections of the Bewcastle Beds in tributaries of the Kirk Beck east of Bewcastle.. 41
FIG. 12. Generalized vertical section of the Main Algal Beds 44
FIG. 13. Comparative vertical sections of the Main Algal Beds 45
FIG. 14. Outcrops of the Bewcastle and Main Algal Beds in Crubinshill Sike 48
FIG. 15. Sketch-map showing outcrops of the Main Algal Beds in Birky Cleugh .. .. *Facing* 60
FIG. 16. Generalized vertical section of the Cambeck Beds 67
FIG. 17. Comparative vertical sections of the Cambeck Beds 71
FIG. 18. Comparative vertical sections of the Middle Border Group and immediately overlying strata 83
FIG. 19. Sketch-map of Riding Grain and its tributaries, showing locations of Middle Border Group sections described in text 85
FIG. 20. Sketch-map showing outcrops of the Kingbridge and Desoglin limestones near Kingbridge Ford 95
FIG. 21. Sketch-map and drawings to illustrate the occurrence of *Pitys primaeva* stumps in the King Water 98
FIG. 22. Sketch-map illustrating the geology of Gilsland Gorge .. *Facing* 108
FIG. 23. Sketch-map showing outcrop of Upper Border Group strata in the River Irthing .. .. *Facing* 126
FIG. 24. Sketch of junction between a thin limestone and underlying coal in strata overlying the Appletree Limestone in the River Irthing .. 127
FIG. 25. Isopachytes and contours of the Thirlwall Seam 130
FIG. 26. Sketch-map showing outcrops of selected horizons in the Upper Border Group in the north-eastern part of the district 136
FIG. 27. Sketch-map showing the geology of the Shilburnhaugh area .. 151
FIG. 28. Comparative vertical sections of the Liddesdale Group 158
FIG. 29. Sketch-map showing the geology of the Liddel Water from Cat Linns to Blae Pot 162
FIG. 30. Ranges of stratigraphically significant fossils in the Lower Carboniferous 167

PAGE

FIG. 31. Distribution of heavy accessory minerals in some Lower Carboniferous sandstones 210
FIG. 32. Comparative vertical sections of the Millstone Grit Series and part of the Lower Coal Measures 223
FIG. 33. Sketch-map showing the main structural elements of the district .. 233
FIG. 34. Rose diagrams to illustrate structural trends in different parts of the district 234
FIG. 35. Sketch-map showing a quartz-dolerite dyke off-set at Short Cleugh 247
FIG. 36. Sketch of a ?multiple dyke exposed in the right bank of the River Irthing 249
FIG. 37. Sketch-maps showing present-day drainage compared with preglacial drainage 260

EXPLANATION OF PLATES

PLATE I Anticline formed by the Penton Limestone at Penton Linns, viewed from the Scottish bank. The cliff a few yards downstream is formed by the Bridge Sandstone, and the Harelawhill Limestone can be seen at the far bend .. .. .. *Frontispiece*

FACING PAGE

PLATE II A. Underside of reddened algal nodule bed displaying typical *Ottonosia*-type growth-forms. Main Algal Eleven, River White Lyne, near Kaysbank
B. Algal colony *in situ* displaying *Collenia*-type growth-forms. The beds are reddened and the dip inverted. Main Algal Eleven. River White Lyne, near Kaysbank 46

PLATE III A. Algal limestone with typical 'nobbly' top. Cambeck Beds. Cam Beck, near Rinnion Hills
B. The Birky Cleugh Limestone and overlying strata, Main Algal Beds, Birky Cleugh 78

PLATE IV A. The Clattering Band, showing colonies of *Lithostrotion* in positions of growth. River Black Lyne opposite Oakshaw Ford Quarry
B. Bedding plane in the Whitberry Band showing abundant *Rugosochonetes cumbriensis* and ostracods. Whitberry Burn 84

PLATE V Comparative vertical sections of the Upper Border Group (excluding the North Tyne District) 105

PLATE VI A. The Spy Rigg Sandstone, Sundayburn Linn, River Irthing, looking north-eastwards
B. The Seven Linns Sandstone at Seven Linns 138

PLATE VII A. Steeply-dipping Harelawhill Limestone (right) and Gastropod Limestone (left) striking downstream towards Blae Pot, Penton Linns, Liddel Water
B. View of the River Irthing (right) at its confluence with Butter Burn, showing meandering and eroded 'terrace-islands' (middle ground): Spy Rigg with its two remanié sandstone blocks forms the skyline 156

PLATE VIII Algae from the Lower Border Group. For full explanation see p. 168 168

PLATE IX Algae from the Cambeck Beds. For full explanation see p. 170 170

PLATE X Secondary quartz growths and algal pellets, Main Algal Beds. For full explanation see p. 171 171

PLATE XI Spores from the Upper Border Group. For full explanation see p. 174 174

PLATE XII Fossils from the Carboniferous. For full explanation see p. 190 190

PLATE XIII Photomicrographs of sedimentary rocks in the Lower Carboniferous. For full explanation see p. 216 216

PLATE XIV Photomicrographs of igneous rocks and associated clastic rocks. For full explanation see p. 244 244

PLATE XV Map showing glacial, fluvio-glacial and ice-retreat features 251

LIST OF SIX-INCH MAPS

The following is a list of six-inch geological maps included in the area of one-inch geological sheet 12 with the initials of the surveying officers and the date of survey for each six-inch map. The officers are: J. B. W. Day, T. Eastwood, D. H. Land, D. A. C. Mills, R. H. Price and F. M. Trotter.

Manuscript copies of the maps are deposited for public reference in the libraries of the London and Leeds offices of the Institute of Geological Sciences.

NY 46 NW	Kirklinton	F.M.T., J.B.W.D.	1921–27, 1953
NY 46 NE	Hethersgill	F.M.T., J.B.W.D.	1927, 1953
NY 47 NW	Penton	F.M.T., T.E., R.H.P.	1922–23, 1952
NY 47 NE	Parkhouse	T.E., R.H.P., J.B.W.D.	1923, 1952–54
NY 47 SW	Moat Common	F.M.T., T.E., J.B.W.D.	1922–23, 1963
NY 47 SE	Solport	T.E., J.B.W.D.	1923, 1952–53
NY 48 SE	Kershopefoot	R.H.P., J.B.W.D.	1952–53
NY 56 NW	Kirkcambeck	F.M.T., J.B.W.D.	1926–27, 1954
NY 56 NE	Craigburn	F.M.T., J.B.W.D.	1926, 1954–60
NY 57 NW	Oakshaw Ford	R.H.P., J.B.W.D.	1952–57
NY 57 NE	Ashy Cleugh	R.H.P., J.B.W.D.	1952–58
NY 57 SW	Lyneholmeford	J.B.W.D.	1952–54
NY 57 SE	Bewcastle	J.B.W.D.	1952–54
NY 58 NW	Kershopehead	R.H.P., J.B.W.D.	1952–53
NY 58 NE	Glendhu Hill	R.H.P., D.H.L.	1952–54
NY 58 SW	Skelton Pike	R.H.P.	1952–57
NY 58 SE	Christianbury Crag	R.H.P., D.H.L., J.B.W.D.	1952–57
NY 66 NW	Gilsland	F.M.T., J.B.W.D.	1926, 1954
NY 66 NE	Tipalt Burn	F.M.T., J.B.W.D.	1925, 1954
NY 67 NW	Irthing Head	J.B.W.D., R.H.P., D.H.L., D.A.C.M.	1954–59
NY 67 NE	Churnsike	J.B.W.D., D.H.L., D.A.C.M.	1954–58
NY 67 SW	Spadeadam Waste	J.B.W.D.	1953–54
NY 67 SE	Wileysike	J.B.W.D.	1954
NY 68 NW	Low Long House	D.H.L.	1954–58
NY 68 NE	Whickhope	D.H.L.	1958
NY 68 SW	Broomylinn	R.H.P., D.H.L., D.A.C.M.	1954–58
NY 68 SE	Christy's Crags	D.H.L., D.A.C.M.	1957–58

UNIVERSITY LIBRARY - 5 OCT 1970

Chapter I

INTRODUCTION

Area and Physical Features

This Memoir describes the geology of the district covered by the Bewcastle (12) Sheet of the One-inch Geological New Series Map of England and Wales (Fig. 1)[1]. The district lies at the northern tip of the county of Cumberland and includes a part of western Northumberland. The Scottish border crosses the north-western corner of the sheet, and the ground beyond it forms part of the Langholm (11) Sheet of the One-inch Geological Map of Scotland. It is not dealt with here but is described in the Langholm Memoir (Lumsden and others 1967).

Within the district the ground rises from below 200 ft O.D. in the low-lying Carlisle Plain in the south-west to over 1700 ft in the high, peaty moorland wastes farther north and north-east. In the north the high ground coincides with the Cumberland–Northumberland border and locally forms the primary watershed

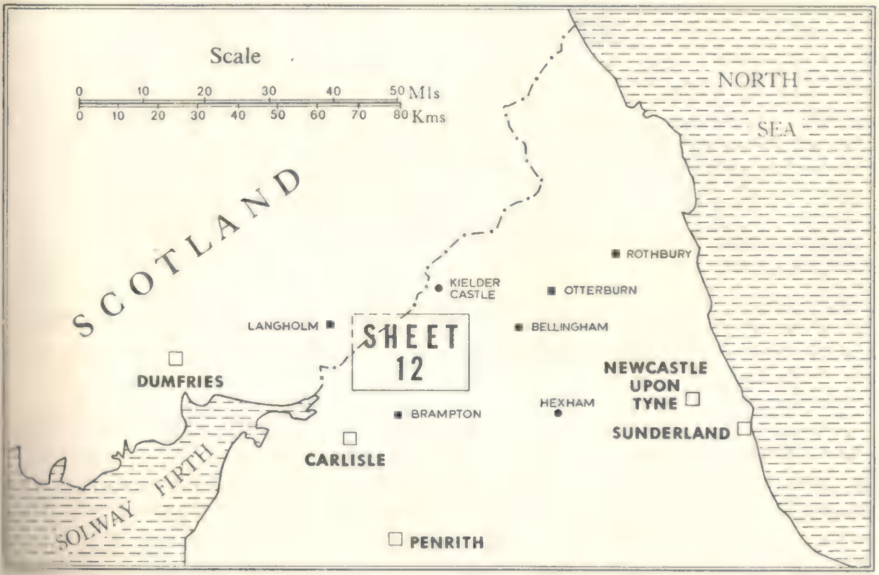


Fig. 1. *Sketch-map showing the location of the Bewcastle District (Sheet 12). The north-west corner of the sheet forms part of the Langholm district (Scottish Sheet 11)*

---

[1] Referred to as 'the district' throughout this memoir.

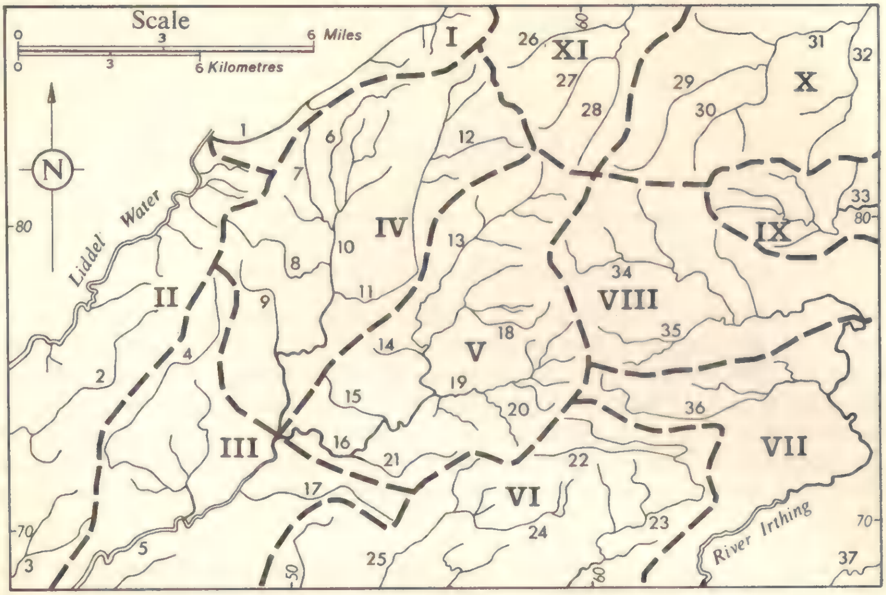


FIG. 2. *Sketch-map showing drainage of the district. Catchment areas to which reference is made in the stratigraphical chapters are numbered as follows:* I *Kershope*, II *Liddel*, III *Lyne*, IV *Black Lyne*, V *White Lyne*, VI *Cam Beck–King Water*, VII *Lower Irthing*, VIII *Upper Irthing*, IX *Chirdon*, X *Whickhope*, XI *Lewis*

Rivers and streams are numbered as follows: 1 *Kershope Burn*, 2 *Carwinley Burn*, 3 *Hall Burn*, 4 *Rae Burn*, 5 *River Lyne*, 6 *Routledge Burn*, 7 *Langley Burn*, 8 *Crook Burn*, 9 *Sleet Beck*, 10 *Bailey Water*, 11 *River Black Lyne*, 12 *The Beck*, 13 *River White Lyne*, 14 *Ellery Sike*, 15 *Whitberry Burn*, 16 *River White Lyne*, 17 *Kirk Burn*, 18 *Ashy Cleugh*, 19 *Kirk Beck*, 20 *White Beck*, 21 *Show Burn*, 22 *Caud Beck*, 23 *King Water*, 24 *Green's Burn*, 25 *Cam Beck*, 26 *Lewis Burn*, 27 *Lishaw Burn*, 28 *Yett Burn*, 29 *Back Burn*, 30 *Humble Burn*, 31 *Whickhope Burn*, 32 *Little Whickhope Burn*, 33 *Chirdon Burn*, 34 *Tarn Beck*, 35 *Hazel Gill*, 36 *Butter Burn*, 37 *Tipalt Burn*

between the River North Tyne, which flows eastwards to the North Sea, and the Cumbrian and Scottish border rivers, which discharge south-westwards into the Solway Firth. The principal rivers and streams are shown in Fig. 2.

The district is predominantly agricultural. Arable crops are important on the more sheltered lower ground bordering the Carlisle Plain, but most of the ground between the plain and the high fells forms rough pasture, much of it poorly drained. Some of the high fells also provide grazing for sheep, but in recent years they have been progressively re-afforested so that the formerly separate forests of Kershope, Kielder and Spadeadam now form a virtually continuous Border Forest covering all but the highest and bleakest parts of the primary watershed.

A number of thin coals were once dug locally, but no working pits now remain. The only other industrial development is a rocket-engine testing site on Spadeadam Waste.

Historically, the area is of considerable interest. It was originally clothed by birch forest, of which ample evidence remains in the peat, and there are signs of ancient British settlements. About 120 A.D. the Romans built the fort of Banna on the sand hill at Bewcastle where the remains of a Norman Castle and the present church now stand; this northerly outpost from the Roman Wall was linked to the larger fortress of Camboglanna (Birdoswald) by the Maiden Way. After the Roman occupation, the fort became an Anglo-Saxon settlement, and a particularly fine example of a cross carved in sandstone was erected during this period in what is now the churchyard; a copy of the cross can be seen in the Victoria and Albert Museum in South Kensington. Still later the place became a Norse colony, and Bewcastle is named after Beuth, a Norse chieftain. Both church and castle were built, or probably rebuilt, from materials obtained from the remains of the Roman fort about 1291 during the reign of Edward I. The castle was destroyed by Cromwell's troops in 1641 and the ruins, still bearing traces of fire, are all that remain.

Previous Research

The earliest six-inch geological survey of the district was carried out by Hugh Miller Jnr., C. T. Clough and J. Clifton Ward between 1870 and 1885, and a hand-coloured map on the one-inch scale was published in 1889. The map was not accompanied by a detailed geological succession nor by a descriptive memoir. Peach and Horne (1903), when dealing with the Canonbie Coalfield, on the Scottish side of the border, described sections in the Liddel Water adjoining the Bewcastle district in the north-west. Smith (1912) described several coals within the district when reporting upon the coal resources of the Carboniferous Limestone of the North of England. The first comprehensive account of the geology of part of the district, however, was published by Garwood (1931), who also produced a coloured map on the one-inch scale showing the structure and stratigraphy. A narrow strip along the southern margin of the district was mapped on the six-inch scale during the 1920's, and subsequently described in the Brampton Memoir (Trotter and Hollingworth 1932). No further major work dealing with the rocks of the Bewcastle district has been published, although Barrett and Richey (1945) mentioned the Liddel Water sections and Johnson (1959) described certain sections in the Tipalt Burn in the extreme south-eastern corner of the district.

Geological Sequence

Formations present within the district are shown in Fig. 3 and are listed below; the grouping of the Carboniferous rocks follows a new classification which is explained in the next chapter.

Superficial Formations (Drift)

Recent and Pleistocene

Peat
Hill Peat
Alluvium
Alluvial Fans
River Terraces
Calcareous Tufa
Glacial Sand and Gravel
Boulder Clay

SOLID FORMATIONS

		Generalized thickness in feet
PERMO-TRIASSIC		
Kirklinton Sandstone	Bright red, poorly micaceous, false-bedded soft sandstone	300
St. Bees Sandstone	Dull red, compact, micaceous sandstone with rare shale bands	500 to 700
?PERMIAN		
St. Bees Shale	Red shales, with rare sandstone bands	200
Basal Conglomerate	Breccia-conglomerate, mainly of Carboniferous fragments in a red sandstone matrix	0 to 30
	Unconformity	
CARBONIFEROUS		
COAL MEASURES		
Upper Coal Measures	Red 'marls', sandstones and seatearths, with rare *Spirorbis* limestones	300
Middle Coal Measures	Not exposed within the district but assumed to be present at depth beneath Upper Coal Measures	
Lower Coal Measures		
MILLSTONE GRIT SERIES	Mainly sandstones and shales, with rare seatearths, thin coals; also limestones, particularly near base. Only the lowest 400 ft are exposed (incompletely) ..	*probably* 1100
CARBONIFEROUS LIMESTONE SERIES		
Upper Liddesdale Group	Sandstones, shales and thick marine limestones, rare seatearths and thin coals	865 to 1400
Lower Liddesdale Group	Sandstones and calcareous shales alternating with thin marine limestones ..	880
Upper Border Group	Marine sandstones, shales and thin limestones, thickening and becoming progressively less marine to the north-east	1910 to 6000 +
Middle Border Group	Marine sandstones, shales and subordinate limestones becoming less marine and more arenaceous to the north-east	1000 to 1500
Lower Border Group		
Cambeck Beds	Shales, sandstones and limestones with abundant shelly faunas and some algae	670
Main Algal Beds	Limestones and shales with abundant algae	280
Bewcastle Beds	Sandstones, shales and limestones with bivalves, ostracods and subordinate algae	600
Lynebank Beds	Shales and limestones with subordinate sandstones and desiccation breccias; fauna dominated by bivalves of *Myalina* type	1400

INTRUSIVE IGNEOUS ROCKS

Quartz-dolerite and allied tholeiite dykes of Tertiary and late Carboniferous or early Permian age.

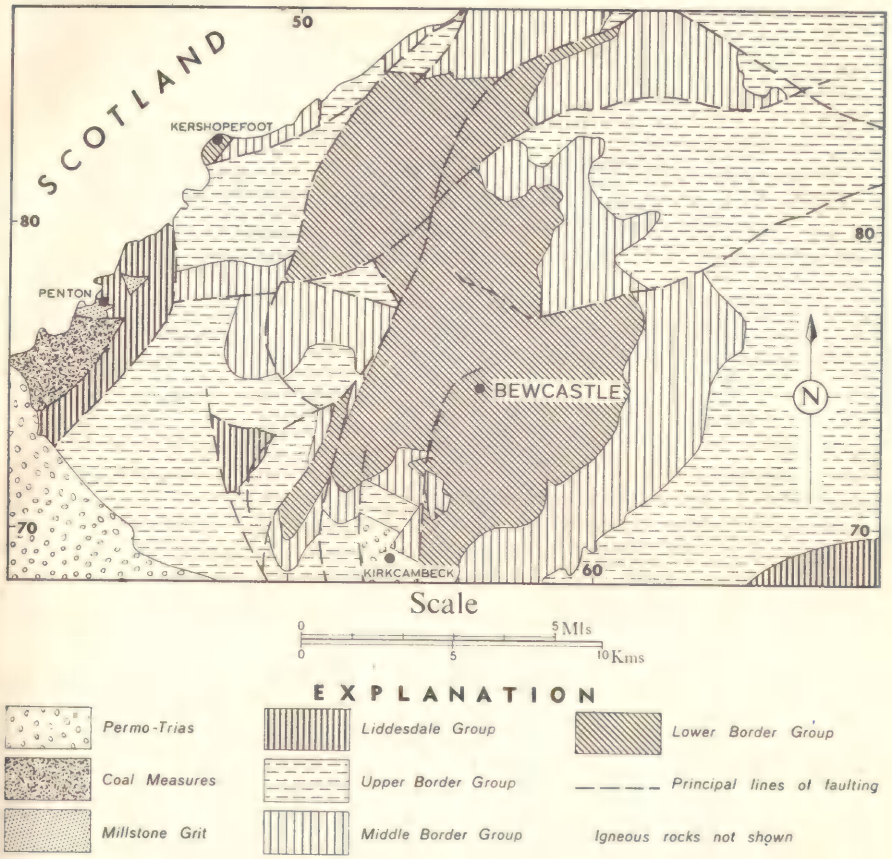


FIG. 3. *Sketch-map showing the distribution of the principal geological formations in the district*

GEOLOGICAL HISTORY

Nothing is known of the pre-Carboniferous history of the district. The lowest rocks exposed belong to the Lower Border Group and consist of marine limestones, shales and sandstones. These rocks were deposited rhythmically in the Northumberland Trough—a flat-bottomed shallow tranquil sea bordered by the land masses of the Southern Uplands to the north and by the Cumbrian and Alston blocks to the south. The trough was connected to a shelf-neritic sea to the south-west and was fed mainly by sediments brought in from the north-east. During Middle Border Group times arenaceous sediments invaded the north-eastern part of the district and occasionally extended into southern and western parts, where they became interdigitated with finer marine muds. This sandy influx decreased in Upper Border Group times and coal-forming vegetation became periodically established in swamp environments. There followed a reversion to marine sedimentation represented by the Liddesdale Group and the Millstone Grit Series. During this time the sea extended southwards across the Alston Block and also breached the Southern Uplands Massif to the north.

This marine phase, like that of Lower Border Group times, ended with an influx of sand from the north-east as represented by the thick sandstones at the top of the Millstone Grit and base of the Coal Measures. Similarly the sandstone phase was followed by a swamp sedimentation that gave rise to the Coal Measures.

Throughout the Carboniferous, cyclic sedimentation appears to have continued without a break, apart from a possible unconformity in the Lower Coal Measures for which G. I. Lumsden (*in* Lumsden and others 1967) has adduced evidence on the Scottish side of the Border.

Lower Carboniferous times were marked by considerable volcanic activity in Scotland, but in the Bewcastle district such activity is represented by a single basalt lava and by a few thin bands of tuff.

Towards the close of Carboniferous times the district was affected by earth-movements, which resulted in widespread folding, faulting and uplift. There followed a lengthy period of subaerial denudation, which ended with the northward encroachment of the sea during the late Permian. The St. Bees Shales were deposited in the sea, followed by St. Bees and Kirklinton sandstones. Rocks younger than the Kirklinton Sandstone are not present within the district, nor is it known if any were ever laid down, although a small area of Lower Lias clays conformably overlies the Trias near Carlisle (Dixon and others 1926, pp. 9, 98).

At some time subsequent to the Triassic period further uplift occurred and faults which affect the Triassic sediments are usually ascribed to widespread Tertiary earth-movements. It is probable, too, that the present drainage system was initiated as a result of Tertiary uplift.

Glacial deposits occur throughout the district; they consist of thick Boulder Clay overlain by heterogeneous sands and gravels, the products respectively of a main glaciation and subsequent retreat. After the close of the glacial period, most of the larger rivers resumed their previous pre-glacial courses, successive erosional stages being marked by flanking terraces and, most recently, by alluvial flood-plains.

The post-glacial climate favoured the growth of peat, not only on the high upland moors of the primary watershed but also in ill-drained hollows on the lower-lying drift-covered plateaux of the Spadeadam area, where depths of peat exceeding 40 ft have been recorded. Many of these bogs are still growing, and the effects of recent drainage for forestry purposes have yet to be felt.

REFERENCES

BARRETT, B. H. and RICHEY, J. E. 1945. Economic geology of the Canonbie Coalfield. *Wartime Pamphlet geol. Surv. Gt Br.*, No. 42.

DIXON, E. E. L., MADEN, J., TROTTER, F. M., HOLLINGWORTH, S. E. and TONKS, L. H. 1926. The geology of the Carlisle, Longtown and Silloth district. *Mem. geol. Surv. Gt Br.*

GARWOOD, E. J. 1931. The Tuedian beds of Northern Cumberland and Roxburghshire east of the Liddel Water. *Q. Jl geol. Soc. Lond.*, **87**, 97–159.

Johnson, G. A. L. 1959. The Carboniferous stratigraphy of the Roman Wall district in western Northumberland. *Proc. Yorks. geol. Soc.*, **32**, 83–130.

Lumsden, G. I., **Tulloch**, W., **Howells**, M. F. and **Davies**, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

Peach, B. N. and **Horne**, J. 1903. The Canonbie Coalfield; its geological structure and relations to the Carboniferous rocks of the north of England and central Scotland. *Trans. R. Soc. Edinb.*, **40**, 835–77.

Smith, S. 1912. *Report of the committee appointed to report upon the Carboniferous Limestone Formation of the north of England, with special reference to its coal measures.* Newcastle upon Tyne.

Trotter, F. M. and **Hollingworth**, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

Chapter II

CARBONIFEROUS CLASSIFICATION AND PALAEOGEOGRAPHY

CLASSIFICATION

ON THE BASIS of the sequence in north Northumberland, particularly in the River Tweed, Tate (1863) proposed a simple fourfold division of the Carboniferous of northernmost England in ascending order as follows: Tuedian, Mountain Limestones, Millstone Grit and Coal Measures. He later (1867) subdivided the Mountain Limestones at the base of the Dun Limestone into a lower Carbonaceous Group and an upper Calcareous Group. Lebour (1875) found that the Carbonaceous and Calcareous groups were not everywhere recognizable entities in Northumberland, and proposed the term Bernician to embrace them both, and this became accepted usage after its adoption by Clough (1889). Tate's classification was nevertheless extended into mid-Northumberland and Liddesdale by Miller (1887), who further subdivided the Tuedian into Lower (including Lower Freestones, Cementstones and Rothbury Limestones) and Upper (Fell Sandstone). Miller also introduced the term Scremerston Coal Series as a synonym for the Carbonaceous Division, but took the upper boundary both at the base of the Dun Limestone (op. cit., p. 5) and at the base of the Redesdale Ironstone Shales (op. cit., p. 42 and Old Series One-inch Geological Sheet 108 S.E.). The latter horizon lies a short distance below the Redesdale Limestone, which Miller correlated with the Dun. This correlation was maintained on the New Series One-inch geological map of the Elsdon district (Sheet 8), which lies to the north-east of the Bewcastle district. Neither Miller nor succeeding workers attempted such close definition of the base of the Scremerston Coal Group, which has generally been taken at the lowest locally workable seam. The underlying Fell Sandstones are consequently an ill-defined group of arenaceous measures nowadays widely believed to be diachronous. The 'Millstone Grit' of all former classifications has similarly lacked definition, being taken to represent an arenaceous group lying between the locally highest limestone at the base and the locally lowest workable Coal Measures seam at the top.

Early classifications took no account of palaeontology until Smith (1911) and Garwood (1910,1913) applied principles of coral-brachiopod zoning to the Calcareous Division of the Bernician. From this zoning arose Fowler's (1926) subdivision into Lower Limestone Group (Dun–Redesdale to Oxford Limestones) Middle Limestone Group (Oxford to Great Limestones) and Upper Limestone Group (Great Limestone to base of 'Millstone Grit').

Trotter and Hollingworth (1932), working in the Brampton district, south of Bewcastle, were, like Lebour, unable to recognize Carbonaceous and Calcareous divisions. Accordingly, they subdivided the Bernician into five groups, of which the two lowest—the Craighill Sandstone Group, with basal Kingwater Limestones, and the Birdoswald Limestone Group—were together equated with the

Scremerston Coal Group (Lower Bernician), while the three highest corresponded to Fowler's Lower, Middle and Upper Limestone groups (Upper Bernician) and were so named.

It is now apparent that existing classifications cannot be satisfactorily applied to the Bewcastle district. The term 'Cementstones' is apt in Northumberland where the measures forming the greater part of the Tuedian are 'especially distinguished by the absence of brachiopods' (Tate 1866), but it is a misnomer in Bewcastle where the equivalent beds are almost entirely marine, including detrital and highly fossiliferous limestones. Garwood's (1931) four subdivisions are nevertheless upheld with only minor modification in the present memoir (Table 1). The remainder of the Tuedian, the ill-defined Fell Sandstone Group of Northumberland, is represented not by a distinct arenaceous unit, but instead by rhythmic sequences of sandstone, shale and thin marine limestone resembling the beds below. Delineation of a Fell Sandstone Group in the Bewcastle district is therefore impossible. The validity of the Scremerston Coal Group is open to doubt even to the east of the Bewcastle district in view of the lack of definition at the base and of Anderson's (1930) evidence to show that the Redesdale–Dun upper limit is a miscorrelation. The group-name is further inapplicable to the Bewcastle district because the typical Scremerston Coal Group lithology is recognizable only in the north-eastern part of the district: elsewhere the equivalent beds are marine, and include only a few thin coals. In this respect they resemble the Lower Bernician of the Brampton district, but in view of the sections in the River Lyne (pp. 115–117), and the Archerbeck Bore there now seems little justification for perpetuating the Craighill Sandstone and Birdoswald Limestone groups proposed by Trotter and Hollingworth.

The desirability of perpetuating the Upper Bernician and its subdivisions is also now open to doubt. The Redesdale–Dun miscorrelation at the base appears to be repeated at the boundary between Lower and Middle Limestone groups for the Bankhouses–Smiddy Limestone is not, according to Johnson (1959), equivalent to the Oxford Limestone as assumed by Trotter and Hollingworth (1932). Moreover, the palaeontological basis for the original subdivision is no longer valid, for Robinson (*in* Westoll and others 1955, p. 81) has recorded D_1 fossils about 1000 ft below the Redesdale Limestone, while Johnson (1959) now draws the D_1–D_2 boundary well below the Oxford Limestone. Still more important is the modern assignment (Johnson and others 1962; Hull 1968) of the whole of the Upper Limestone Group together with part of the old 'Millstone Grit' to the Namurian Series (Millstone Grit Series *sensu stricto* of other parts of England and of Wales).

In this memoir, therefore, the Dinantian or Lower Carboniferous, that is the succession below the Catsbit or Great Limestone, is divided into a tripartite Border Group below and a bipartite Liddesdale Group above (Table 1).

The Lower Border Group, extending up to the base of the Whitberry Band, corresponds closely to the Cementstone Group as defined by Garwood (1931), but includes the Rothbury Limestones and part of the Fell Sandstone Group of Northumberland classifications. The Middle Border Group, extending up to the base of the Clattering Band, includes parts of the Fell Sandstone and Scremerston Coal groups. The Upper Border Group is equivalent to most of the remainder of the Scremerston Coal Group. The division between the Upper

TATE 1867	LEBOUR 1875	MILLER 1887	FOWLER 1926 - 1936 - 1966		TROTTER AND HOLLINGWORTH 1932	PRESENT CLASSIFICATION			
COAL MEASURES	COAL MEASURES		COAL MEASURES	UPPER GROUP		UPPER COAL MEASURES		WESTPHALIAN	UPPER CARBONIFEROUS OR SILESIAN
				MIDDLE GROUP	MIDDLE COAL MEASURES	MIDDLE COAL MEASURES			
				LOWER GROUP		LOWER COAL MEASURES			
MILLSTONE GRIT	MILLSTONE GRIT		MILLSTONE GRIT		LOWER COAL MEASURES	MILLSTONE GRIT SERIES Catsbit Limestone		NAMURIAN	
CALCAREOUS DIVISION	BERNICIAN	CALCAREOUS DIVISION	UPPER LIMESTONE GROUP Great Limestone		UPPER LIMESTONE GROUP Great Limestone				
			MIDDLE LIMESTONE GROUP Oxford Limestone		MIDDLE LIMESTONE GROUP Bankhouses=Smiddy Lst.	UPPER LIDDESDALE GROUP Low Tipalt Limestone		VISÉAN	LOWER CARBONIFEROUS OR DINANTIAN
Dun Limestone		Dun Limestone	LOWER LIMESTONE GROUP Dun Lst	Redesdale Lst	LOWER LIMESTONE GROUP Naworth Limestone	LOWER LIDDESDALE GROUP Naworth Bryozoa Band			
CARBONACEOUS DIVISION		CARBONACEOUS DIVISION or SCREMERSTON COAL SERIES	SCREMERSTON COAL GROUP		BIRDOSWALD LST GROUP Lanercost Limestone	UPPER BORDER GROUP Clattering Band			
		Lewisburn Coals			CRAIGHILL SST GROUP Kingwater Limestones				
TUEDIAN	TUEDIAN	FELL SANDSTONES	FELL SANDSTONE GROUP		FELL SANDSTONE GROUP	MIDDLE BORDER GROUP Whitberry Band			
		Rothbury Limestones			Rothbury Limestones	LOWER BORDER GROUP	CAMBECK BEDS *L. Antiquatonia* Band		
		CEMENTSTONES	CEMENTSTONE GROUP		CEMENTSTONE GROUP		MAIN ALGAL BEDS M.A1	TOURNAISIAN	
		LOWER FREESTONES					BEWCASTLE BEDS Bogside Limestone		
							LYNEBANK BEDS		

TABLE I. *Carboniferous classification*

Border and Liddesdale groups is made at the base of the Dinwoodie Beds of the Archerbeck Borehole, where a distinct faunal break is recorded (Wilson 1961). The Dinwoodie Beds, which are represented in the bore by highly fossiliferous marine shales 180 ft below the Kinmont Limestone, are represented at outcrop by the Goat Island Limestone. They are tentatively correlated by Lumsden and Wilson (1961, p. 11) with the Bryozoa Band beneath the Naworth Limestone (and in the following account are referred to as the Naworth Bryozoa Band). The Liddesdale Group is divided at the Callant (approximately Low Tipalt) Limestone into Lower and Upper groups corresponding broadly to the Lower and Middle Limestone groups of the old classifications.

To conform with practice in other parts of England and Wales the Millstone Grit Series is now equated with the Namurian and thus extends from *Cravenoceras leion* at the base to *Gastrioceras subcrenatum* at the top. The lower boundary is taken at the base of the Great Limestone (Johnson and others 1962); the upper lies about two thirds the way up in the former 'Durham Millstone Grit', though the type fossil has yet to be found in north-east England (Mills and Hull 1968).

PALAEOGEOGRAPHY

The Bewcastle district straddles the south-westerly axis of the Carboniferous sedimentary basin known as the Northumbrian Trough, margined to the north-west by the Southern Uplands massif and to the south by the rigid lower Palaeozoic blocks of Cumbria and Alston. Throughout Lower Carboniferous times the sea lay to the south-west, while the principal source of sediment seems to have been a land mass to the north-east in the area now covered by the North Sea. The thick and laterally variable cyclic deposits of Yoredale type indicate frequent incursions by this sea into a vast, shallow, tidal firth gradually subsiding in response to isostatic pressures and fed by a major river system draining the provenance area.

Although the Northumbrian Trough seems to have existed as a separate entity throughout most of Lower Carboniferous times it was linked in Lower Border Group (Cementstone) times with the Scottish Midland Valley Trough via the Berwickshire coast; during Upper Carboniferous times a second link was established across the Southern Uplands via Thornhill and Sanquhar. At least 10 000 ft of Carboniferous sediments of Yoredale type are known to have been deposited in the Bewcastle district, quite apart from any basal beds that may lie concealed. There is, in addition, a considerable thickness of Millstone Grit and Coal Measures strata cut out by faulting, so that the total thickness of Carboniferous rocks originally deposited may have amounted to 14 000 or 15 000 ft in the centre of the trough.

The contemporaneous northern shore-line of the trough is seen to be roughly coincident with the modern north Solway shore, for at Rerrick, Colvend and Kirkbean measures equivalent in age to the Lower and Middle Border groups of Bewcastle include a substantial proportion of marginal rudaceous sediment (Craig 1956; Craig and Nairn 1956). Around Bewcastle, the lowest beds exposed comprise more than 3000 ft of rhythmically deposited muds, sands and marine limestones of the Lower Border Group; rudaceous beds are conspicuously absent but faunal changes and differing algal growth-forms indicate a progressive shallowing of the shelf-neritic sea towards the coastline nearby to the north-west. Within the limits of the district the Lower Border Group is predominantly marine and yields an abundant coral-brachiopod-bivalve fauna interleaved with algal phases, but farther to the north-east, in Northumberland, the equivalent Cementstones become progressively less fossiliferous and less marine although algae are recorded as far east as Rothbury.

Towards the close of Lower Border Group times the Northumbrian Trough comprised a sediment-filled shallow, almost land-locked, firth with well-defined northern and southern shores that tended to close towards a relatively narrow seaward outlet in what is now the Solway Firth (George 1958, pl. 15): algae flourished on tidal mudflats that periodically supported abundant, shelly faunas. A sudden uplift, possibly accompanied by a climatic change in the provenance area to the north-east, then resulted in an influx of arenaceous material forming the massive Fell Sandstones—a facies that remains uniform for fifty miles between the coast of Northumberland and the Cumberland border. It enters the north-east corner of the Bewcastle district where it is represented by sandstone in the Cambeck Beds and in the lower part of the Middle Border Group, but between the North Tyne–Irthing watershed and the River White Lyne south-west of Bewcastle village the sandstones wedge out and interdigitate with marine muds and limestones. The heavy mineral assemblage of the Fell Sandstones, although rudimentary, differs from that of underlying sands of the Northumberland Cementstone Group (Robson 1956, pp. 251–4).

The constant velocity of the currents responsible for transporting this tremendous mass of homogenous material over such a distance must be accounted for. Most estuaries widen and deepen to seaward and thus have an increased cross-sectional area and decelerating currents with consequent deposition of finer sediment with increasing distance from the provenance area. The Northumbrian Trough, however, seems to have narrowed seaward, and this factor, together with gradual seaward deepening, may have tended to produce a constant cross-sectional area (and hence a constant current velocity) across the firth at least as far as Bewcastle, where the increased gradient of the floor towards the south-west resulted in slower currents and deposition of finer material interleaved with periodic surges of sand.

At the beginning of Upper Border (approximately Scremerston Coal) Group times, the massive influx of sand into the trough ceased and coal-forming swamp conditions were periodically established across Northumberland. They extended at times into Cumberland, but coals are there thinner and fewer, while marine beds are thicker and more abundant. There seems to have been little change in the configuration of the trough, but during this period compensatory movement appears to have been initiated along two major faults in the centre and aligned with the axis of the trough (Chapters V and XII). The resultant downwarping gave rise to a local accumulation of at least 6000 ft of Upper Border Group sediments.

The beginning of Liddesdale Group times is marked by widespread marine transgression, which first inundated the Northumbrian Trough and the Vale of Eden, and then the Alston Block. Marine conditions then continued to prevail, with periodic emergence marked by rare coals, until well into Namurian times, when another influx of sand reflects further rejuvenation of the land mass to the north-east. Extensive deposition of sand continued over most of the trough into

Lower Coal Measures times. By then the depositional area was probably continuous with other Coal Measures areas across the Pennines to the south and the Southern Uplands to the north, for the Middle Coal Measures of the Canonbie area (Lumsden and others 1967) seem to be typical delta-swamp deposits of the period. Some uplift and emergence may have taken place in late Carboniferous times, within the district or not far away, for the reddening of Upper Coal Measures strata suggests either oxidation *in situ* of iron compounds beneath a land surface, or derivation of red sediments from a nearby source that was subject to oxidation.

REFERENCES

ANDERSON, W. 1930. In *Summ. Prog. geol. Surv. Gt Br.* for 1929, pt. 1, 67–8.

CLOUGH, C. T. 1889. The geology of Plashetts and Kielder. *Mem. geol. Surv. Gt Br.*

CRAIG, G. Y. 1956. The Lower Carboniferous outlier of Kirkbean, Kirkcudbrightshire. *Trans. geol. Soc. Glasg.*, **22,** 113–32.

—— and NAIRN, A. E. M. 1956. The Lower Carboniferous outliers of Colvend and Rerrick shores, Kirkcudbrightshire. *Geol. Mag.*, **93,** 249–56.

FOWLER, A. 1926. The geology of Berwick-on-Tweed, Norham and Scremerston. *Mem. geol. Surv. Gt Br.*

—— 1936. The geology of the country around Rothbury, Amble and Ashington. *Mem. geol. Surv. Gt Br.*

—— 1966. The stratigraphy of the North Tyne basin around Kielder and Falstone, Northumberland. *Bull. geol. Surv. Gt Br.*, No. 24, 57–104.

GARWOOD, E. J. 1910. The geology of Northumberland and Durham. *Geology in the Field: Jubilee Vol. Geol. Assoc.* (1858–1908), 661–97.

—— 1913. The Lower Carboniferous succession in the north-west of England. *Q. Jl geol. Soc. Lond.* **68,** 449–586.

—— 1931. The Tuedian Beds of northern Cumberland and Roxburghshire east of the Liddel Water. *Q. Jl geol. Soc. Lond.* **87,** 97–159.

GEORGE, T. N. 1958. Lower Carboniferous palaeogeography of the British Isles. *Proc. Yorks. geol. Soc.*, **31,** 227–318.

HULL, J. H. 1968. The Namurian stages of north-eastern England. *Proc. Yorks. geol. Soc.*, **36,** 297–308.

JOHNSON, G. A. L. 1959. The Carboniferous stratigraphy of the Roman Wall district in western Northumberland. *Proc. Yorks. geol. Soc.*, **32,** 83–130.

—— HODGE, B. L. and FAIRBAIRN, R. A. 1962. The base of the Namurian and of the Millstone Grit in north-eastern England. *Proc. Yorks. geol. Soc.*, **33,** 341–62.

LEBOUR, G. A. 1875. On the limits of the Yoredale Series in the north of England. *Geol. Mag.*, **2,** 539.

LUMSDEN, G. I., TULLOCH, W., HOWELLS, M. F. and DAVIES, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*, i-xiii, 1–354.

—— and WILSON, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfries-shire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

MILLER, H. 1887. The geology of the country around Otterburn and Elsdon. *Mem. geol. Surv. Gt Br.*, i-viii, 1–147.

MILLS, D. A. C. and HULL, J. H. 1968. The Geological Survey Borehole at Woodland, Co. Durham (1962). *Bull. geol. Surv. Gt Br.*, No. 28, 1–37.

NAIRN, A. E. M. 1956. The Lower Carboniferous rocks between the River Esk and Annan, Dumfriesshire. *Trans. geol. Soc. Glasg.*, **22,** 80–93.

ROBSON, D. A. 1956. A sedimentary study of the Fell Sandstones of the Coquet valley, Northumberland. *Q. Jl geol. Soc. Lond.*, **112,** 241–58.

SMITH, S. 1911. The faunal succession of the Upper Bernician. *Trans. nat. Hist. Soc. Northumb.*, **3,** 591–645.

TATE, G. 1863. Fauna of the Mountain Limestone formation on the Berwickshire coast, with a preliminary notice of the succession of the strata on the eastern borders. *Proc. Berwicksh. Nat. Club* for 1856–63, 149–56.

—— 1867. Miscellanea geologica for 1866. *Proc. Berwicksh. Nat. Club*, **5,** 283–9.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

WESTOLL, T. S., ROBSON, D. A. and GREEN, R. 1955. Guide to the geology of the district around Alnwick. *Proc. Yorks. geol. Soc.*, **30,** 61–100.

WILSON, R. B. 1961. Palaeontology of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 90–106.

Chapter III

LOWER BORDER GROUP

GENERAL ACCOUNT

THE LOWER BORDER GROUP extends from the base of the Carboniferous up to the base of the Whitberry Band and is thus synonymous with the Lower Tuedian or Cementstone Series of the Bewcastle district as defined by Garwood (1931, p. 100), though it is not the precise equivalent of the Cementstone Group as defined in Northumberland (p. 9).

The Group is divided as follows:

	ft
CAMBECK BEDS	670
MAIN ALGAL BEDS	280
BEWCASTLE BEDS	600
LYNEBANK BEDS	1400

These divisions closely follow those originally proposed by Garwood (op. cit.) though the thicknesses are considerably revised. Moreover, the divisions are here more precisely defined and the name 'Main Algal Beds' replaces Garwood's 'Main Algal Series' to accord with local stratigraphical nomenclature. The succession and principal named beds are shown graphically in Figs. 5–17.

Lithologically, the Lower Border Group differs considerably from the broadly equivalent Cementstone Group of north Northumberland and Berwickshire. Although rhythmic limestone-shale-sandstone sedimentation is common to both, there is a contrast between the barren, argillaceous, chemically-precipitated, commonly dolomitic 'cementstones' typical of the Tweed Valley and the shelly, marine or near-marine, detrital limestones of Bewcastle. The beginnings of lateral change from fresh-water or estuarine to marine conditions can be detected near Alnwick and Rothbury where beds at the top of the local 'Cementstone Group' have yielded sparse rhynchonellids (Carruthers and others 1930, pp. 12–3) and include thick algal limestones (Garwood 1931, pp. 135–6; Fowler 1936, pp. 6–12).

Neither the base of the Carboniferous nor the underlying rocks are exposed within the Bewcastle district. To the north-west, in Liddesdale, the Birrenswark Lavas—assigned by Nairn (1956, p. 84) to the Old Red Sandstone and by Lumsden and others (1967, p. 51) to the lowermost Carboniferous—are directly overlain by the thick Whita Sandstone which is succeeded in turn by measures apparently equivalent to the Bewcastle Beds. It is therefore possible that part at least of the Whita Sandstone is of the same age as the Lynebank Beds of the Bewcastle area, though the possibility of a sandstone of Whita type being present at depth beneath the Lynebank Beds cannot be ruled out.

Because of faunal similarities with equivalent strata in Westmorland, Garwood (1931, p. 105) believed that the Cementstone Series represented zones Z_2 to C_2 of Vaughan's (1905) coral-brachiopod zonal sequence. Specifically he took the presence of *Pustula interrupta* low in the Lynebank Beds to indicate a Z_2 age, as this fossil was characteristic of Z_2 beds in the Bristol district. The basal Cambeck fauna (op. cit., p. 112) was held to be equivalent to his *Athyris glabristria* Zone (low C_2) of Westmorland, and the fossil assemblage from Cambeck Beds just below the Whitberry Band (op. cit., p. 116) was equated with the *Michelinia* (high C_2) Zone of the Arnside area.

Palaeontological results of the resurvey (p. 166) are in broad agreement with Garwood's zonal scheme. The lowest Lynebank Beds are probably of C_1 age, and the remainder of the Lynebank Beds and younger strata up to the base of the Cambeck Beds are probably C_1. This implies the presence of a total thickness of at least 2280 ft of Tournaisian strata, contrary to the view expressed by George (1958) that no strata older than Viséan occur in northern England. This thickness may be even greater if part of the Cambeck Beds is also assigned to C_1, but the position of this division within the zonal scheme is not yet certain (p. 169).

The presence of calcareous algae in nodular bands or encrusting reefs is a characteristic feature of the Lower Border Group. Garwood (1931, p. 102) considered them to "constitute the most important algal development so far recorded in the British Carboniferous rocks", and believed, as did Fowler (1936, p. 6) that they denoted a particular 'lagoonal' environment. However, it is now thought (p. 177) that many of these primitive aquatic plants flourished either in comparatively shallow open water of varying salinity, or on mudflats within an inter-tidal zone. Thus the term 'lagoonal', in so far as it implies land-locked areas of sea, is misleading, and should be avoided.

Modern algae are classified according to their reproductive organs and processes, but fossils have been classified on a growth-form basis. In the present account reference is made only to the simpler growth-forms described by Anderson (1950), and a detailed account of Tournaisian fossil algal floras and their sedimentary environment will be found in Chapter VII.

Oolitic pellet beds (algoolites, see p. 178) occurring as thin bands, are also characteristic of the Lower Border Group. The ooliths are distinguished in thin section from inorganic ooliths by the presence of a common outer casing or test; they are generally associated with secondarily-derived algal breccias and with bands of algal pellets of '*Osagia*' type. Garwood (1931, pp. 100, 110–2) distinguished a single, thin oolite band within the Main Algal Beds ('Series'), but there are several beds of algoolite in each of the other divisions of the Lower Border Group.

Concentric-layered, nodular '*Ottonosia*' and '*Osagia*' growths are the commonest algal forms present. They are particularly well developed in the Main Algal and Lynebank beds, and commonly occur in limestones, mudstones and shales. They are less common in sandy shales and very rare in calcareous sandstones where they may possibly be derived. Most of the nodules invest nuclei formed by sand grains or, more commonly, by fragments of ostracod, bivalve or brachiopod shells. Garwood (1931, p. 110, pl. ix) noted that specimens of *Orthoceras* (*Euloxceras*) *breyni*[1] form the nuclei of many of the large, compound nodules

---

[1] Throughout this memoir the names of authors of fossil species are given only if they do not appear in the faunal lists on pp. 191 to 199.

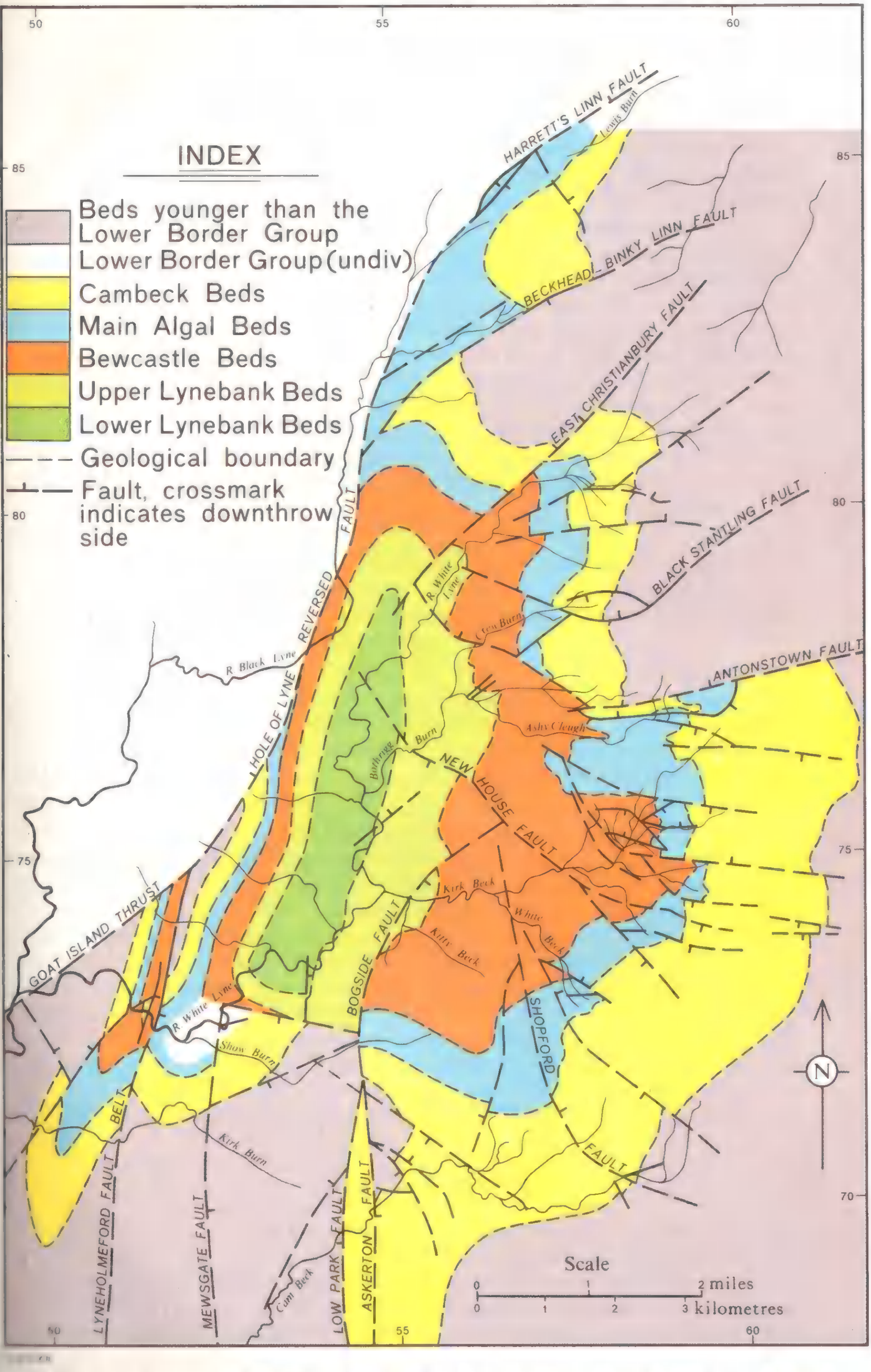


FIG. 4. *Sketch-map showing distribution of Lower Border Group strata east of the Hole of Lyne Fault*

comprising his 'Main Reef' (p. 45) and during the resurvey the presence of algal-encrusted orthoceratids and bellerophontids was found to be characteristic of this horizon as well as of the overlying limestone over considerable areas.

In the north-western part of the district, in what are believed to have been the intertidal zones near the contemporaneous shoreline, the predominant growth-form is the sessile '*Collenia*'-type in which the growths commenced as encrustations and later extended upwards as protuberances in response to overhead light, the presence of adjacent growths, and local sedimentation. Such forms are common in the Main Algal Beds of The Beck and Riding Grain, where the algal limestones so constituted seem to have undergone little or no compaction or compression after formation and burial. They are, however, rare in the central part of the district. The common association of fossil algae with authigenic quartz and their affinity to vulcanism has been noted by Anderson (1950, p. 14). Across the Scottish border to the west of the Bewcastle district, there were many volcanic vents active during Lower Border Group times, although only one neck and two bands of tuff have been noted on the English side. Moreover, the Old Red Sandstone lavas of the Cheviots formed part of the provenance area to the north-east and may have supplied some of the minerals necessary for strong algal growth.

The use of algae for correlation is limited, because the same species occur repeatedly throughout both the Lower and Middle Border groups, although with the exception of the ubiquitous *Girvanella sp.* they have not been recorded in this district above the Clattering Band.

Serpulid worms are commonly associated with algae in both nodular and reef forms throughout the Lower Border Group. The reef-like masses are composed almost exclusively of multitudes of intertwined calcareous tubules of *Serpula advena* and attain thicknesses of several feet. Although there are many such bands their value for purposes of correlation is limited by their lenticular nature.

The prolific shelly fauna is a more reliable guide to correlation, though there are few diagnostic species, particularly among the bivalves, most of which are widely-ranging forms. The most valuable of the brachiopods is *Antiquatonia* ['*Dictyoclostus*'] *teres*, which is virtually restricted to the Lower Border Group, and is of diagnostic abundance at certain horizons. *Pustula interrupta*, *Athyris glabristria* and *Syringothyris exoleta* similarly appear to be restricted to parts of the Lower Border Group. *P. interrupta* is rare and occurs low in the Lynebank Beds; *S. exoleta* is common in the Cambeck Beds above the Upper *Antiquatonia* Band tending to become abundant in bands (e.g. *Syringothyris* Limestone) associated with *Schuchertella* ['*Derbyia*'] *ambigua*; *Athyris glabristria*, the type species of the *A. glabristria* Zone of Ravenstonedale (Garwood 1913), occurs in the Main Algal Beds, but is mostly found in the overlying Cambeck Beds.

LYNEBANK BEDS

Garwood (1931, p. 100) originally defined the Lynebank Beds as extending from the lowest measures seen in Ellery Sike up to and including the 'Lower *Dictyoclostus teres* Band' (Bogside Limestone of the new classification). In this account, however, the top of the group is taken at the base of the Bogside Limestone, and a subdivision is proposed on lithological grounds. The Lower

Lynebank Beds, extending up to the top of the Rawney Limestone, consist of limestone, shale and sandstone in rhythmic alternations of 'Yoredale' type, whereas the Upper Lynebank Beds are virtually devoid of sandstone and comprise alternations of limestones (mostly thin and dolomitic) with shales that are locally calcareous (Fig. 5). The measured thickness of the lower subdivision is 600 ft, and that of the upper subdivision about 800 ft, though the last figure is approximate as sections are incomplete and may be faulted. The combined thickness is appreciably less than the 1800 ft (less 60 ft to allow for the Bogside Limestone) estimated by Garwood (1931, p. 108).

Beds of brecciated mudstone commonly 1 to 2 ft thick are characteristic of, although not confined to, the Lynebank Beds. They consist of small, angular fragments of greenish, calcareous mudstone in a grey mudstone matrix. In each breccia all the fragments appear to be derived from a single bed. Both lower and upper limits of individual beds are generally sharp, but at one locality the top of a bed appears to transgress the base of the overlying shale, possibly through slumping. These breccias are best attributed to the desiccation and subsequent erosion of mud-flats in shallow tidal water.

A single bed of dark, calcareous tuff or tuffaceous limestone, 1 to 2 ft thick, is locally present beneath the Rawney Limestone, and is associated with algoolite bands. The underlying shales are sharply contorted, and the overlying shales with thin limestones appear to have been disturbed, possibly by earthquake action.

Garwood (1931, pp. 103–4) distinguished a single algal limestone associated with serpulid bands near the base of the Lynebank Beds in Ellery Sike. Moreover, algal bands are common throughout the sequence, as are serpulids, which occur either as thin bands or as 'nests'.

Bivalves of *Myalina* type are dominant amongst the Lynebank fauna; brachiopods are less common. The lowest exposed limestone, 25 to 30 ft thick, contains fragments and rare whole specimens of *Antiquatonia teres* and other brachiopods. *A. teres* persists throughout the sequence, but is nowhere as abundant as in the Bogside Limestone at the base of the overlying Bewcastle Beds. *Pustula interrupta*, believed to be diagnostic of the Z_2 sub-zone, occurs in the Ellery Sike Limestone and in shales in the same part of the sequence near the mouth of Bothrigg Burn; according to Garwood it is also found at a comparable horizon in the River White Lyne at Cat Scar. Ostracods are abundant at all levels, but especially in the shales overlying the Common Flat Limestone, where they are crowded in thin bands several inches thick.

The Lynebank Beds occupy the core of the Bewcastle Anticline forming an oval tract of low-lying land flanked by the higher ground of the Bewcastle Fells to east and north, but open to the south. This tract is drained by the River White Lyne and its tributaries and also by the River Black Lyne upstream from its confluence with the Bailey Water. The best sections through the Lower Lynebank Beds commence in Ellery Sike and continue downstream beyond its junction with the River White Lyne around Nixonstown. The lower part of the same sequence is equally well exposed in the River White Lyne along the strike about 300 yd farther north. The Upper Lynebank Beds are moderately well exposed in the River White Lyne downstream from Greenholme continuing past Kirkbeckstown up the Kirk Beck. All these sections are on the eastern limb of the Bewcastle Anticline. On the western limb, where dips are steep or locally even

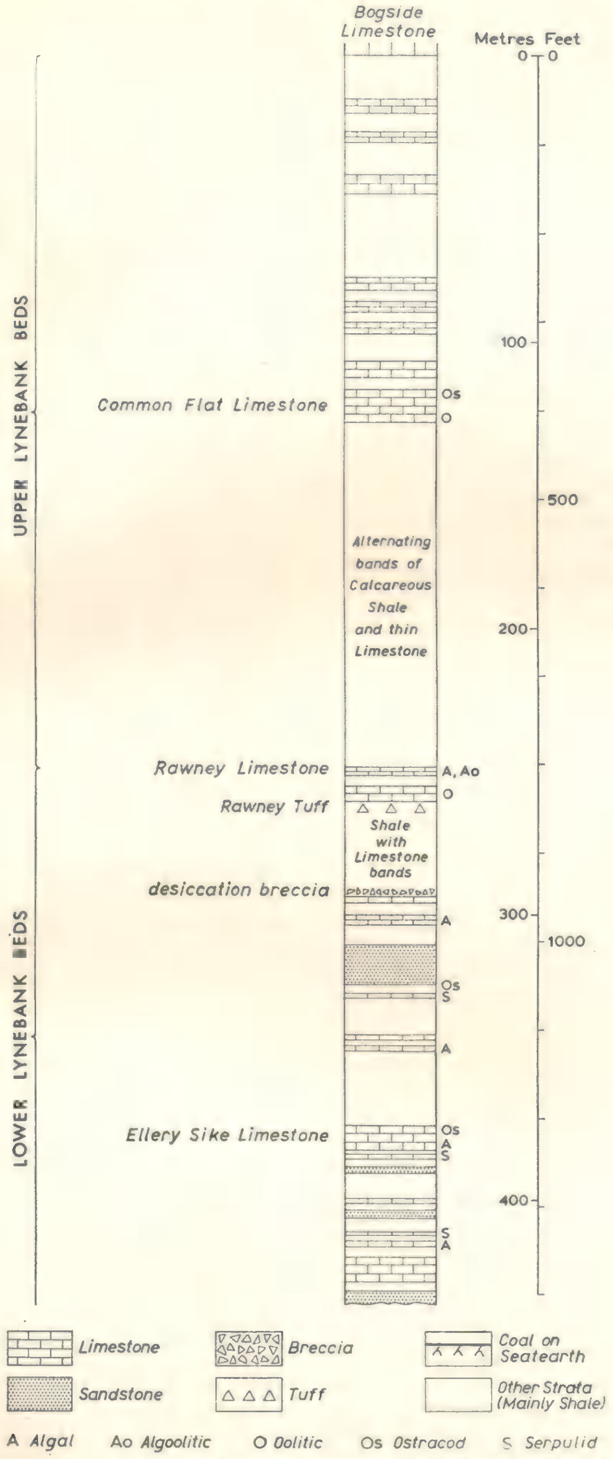


FIG. 5. *Generalized vertical section of the Lynebank Beds*

inverted, there are long continuous sections in the River Black Lyne, near Holmehead and Hole of Lyne farms, and partial or discontinuous sections in the River White Lyne upstream from Wellington Gate, near Murrayholme and Crook, and also upstream from the Flatt, where many of the limestones are algal.

LYNEBANK BEDS: DETAILS

BLACK LYNE CATCHMENT

Routledge Burn. The northernmost outcrop of the Lynebank Beds is in the Routledge Burn where they form the core of a steep-limbed anticline. Only the measures immediately underlying the Bogside Limestone can be seen (loc. 1)[1], and a typical section [5200 8338] is:

	ft
Limestone, fine-grained grey; microfossils, *Serpula sp.*	½
Shale, dark grey calcareous ..	1
Not exposed	2
Shale, hard dark grey; limestone partings	¾
Shale, dark grey; calcareous bands	1

River Black Lyne (loc. 2). In a 500 yd stretch immediately west and south of Hole of Lyne, the river follows a north-north-easterly course along the strike of the Common Flat Limestone. Both upstream and downstream the river traverses higher strata up to the Kitty Beck Limestone in the Bewcastle Beds (p. 39). These strata form part of the western limb of the Bewcastle Anticline and dips are commonly near-vertical and the beds locally overturned. Approaching the Hole of Lyne Fault, to the west of both Holmehead and Hole of Lyne, the succession is complicated by subsidiary parallel faults, and to north-west of Hole of Lyne by folding and cross-faults, at least one of which is transcurrent.

The sequence consists almost entirely of calcareous shales with subordinate limestones and rare thin sandstones. Several of the shales are contorted—apparently penecontemporaneously—and decalcification breccias occur at various levels. Bivalves and ostracods occur throughout and there are several thin algoolite bands and serpulid horizons. *Antiquatonia teres* is rare.

The Common Flat Limestone, exposed high in the left bank [5431 7828], is at least 20 ft thick and is a dark grey massive rock which includes shaly bands. The top of the limestone is seen in the river bed [5437 7849] to contain abundant serpulids with an oolite band slightly lower down. Upstream, at the bend [5443 7874], the limestone is reef-like and is probably algal. Its outcrop is shifted 57 ft by a sinistral tear fault.

The beds overlying the Common Flat Limestone are best seen in the Holmehead reach, although a similar sequence can be made out upstream from Hole of Lyne. The Holmehead section is given in detail in Appendix I and shown graphically in Fig. 6.

WHITE LYNE CATCHMENT

The full known thickness of the Lynebank Beds is exposed in a nearly continuous section in the River White Lyne and its tributaries (Fig. 6). All the principal sections lie on the eastern limb of the Bewcastle Anticline. The lowest beds are well exposed in Ellery Sike and in the River White Lyne, south-east of Wellington Gate. They are followed in upward succession by sections in the Bothrigg Burn and in the River White Lyne west of Nixonstown. The measures forming the middle and upper parts of the Lynebank Beds can be seen in the River White Lyne, near Greenholme, and in strike-sections downstream from Kirkbeckstown. The measures above the Common Flat Limestone are also exposed in the lower reaches of the Kirk Beck.

Ellery Sike (loc. 3). The sequence in Ellery Sike was originally described by Garwood (1931, pp. 103–6). It has been re-measured and is given in full in Appendix I (p. 286) together with the upward continuation of the succession exposed in the River White Lyne downstream from the Ellery Sike confluence. Moreover, the following account

---

[1] A complete list of the fossils collected during the resurvey, with their localities (numbered loc. 1, loc. 2, etc.) is given on pp. 191 to 205.

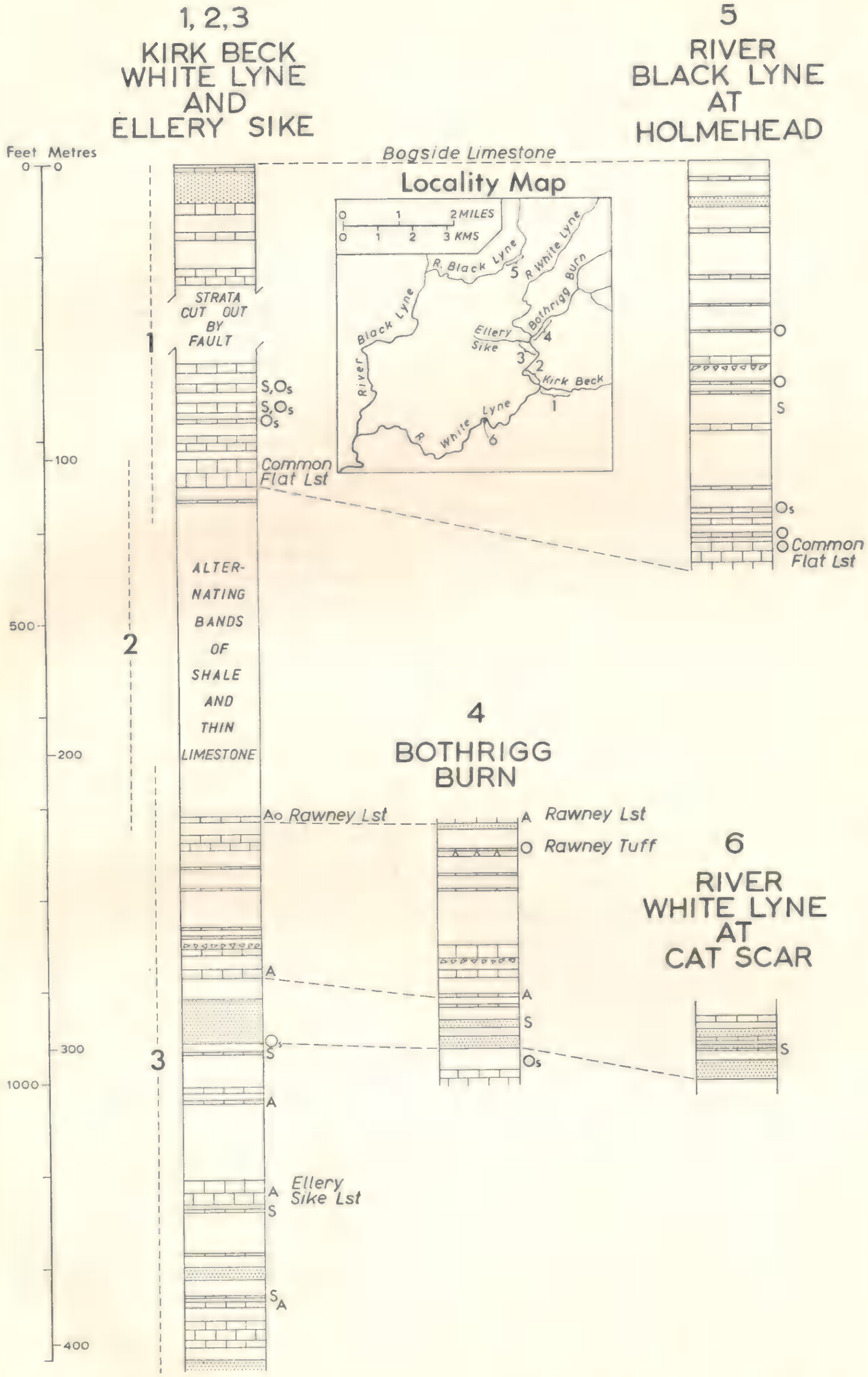


FIG. 6. *Comparative vertical sections of the Lynebank Beds. For key see Fig. 5*

of the Ellery Sike sequence is augmented by reference to a complementary set of exposures in the River White Lyne upstream from the confluence.

The base of the exposed sequence is formed by 10 ft of flaggy sandstone cropping out in Ellery Sike [5433 7584]. It is there succeeded, after an unexposed interval of about 10 ft, by 28 ft of shaly limestone containing *Antiquatonia teres* and *Pustula sp.* This limestone is seen also in the left bank of the River White Lyne where it lies at the base of the complementary sections [5438 7618] as follows:

	ft
Limestone, grey earthy	1½
Shale; bed of bivalve spat associated with abundant ostracods at top	15
Limestone; sparse *A. teres* ..	10

The shales of this section are not exposed in Ellery Sike, where the next bed seen in upward succession is a nodular algal limestone at least 1½ ft thick [5441 7582]. It contains *Ortonella furcata*, *O. kershopensis* and ?*Garwoodia*, and is the lowest known algal horizon in the district (Garwood 1931, p. 104). The bed is exposed in the left bank of the River White Lyne [5442 7607] where it is 8 ft thick and contains *Serpula sp.* and algal festoon structures.

The overlying sequence up to the Ellery Sike Limestone is continuously exposed in the River White Lyne, and partially in Ellery Sike. It includes a number of thin limestones containing *Serpula advena* and two beds of greenish breccia of uncertain origin (p. 18). A serpulid limestone underlying the Ellery Sike Limestone in Ellery Sike [5445 7583] is not present in the River White Lyne, but *Serpula sp.* is fairly common there in the lower part of the Ellery Sike Limestone.

The Ellery Sike Limestone is equivalent to the *Pustula interrupta* Beds of Garwood (1931, pp. 105–6). Seen in the left bank of Ellery Sike [5446 7583], it is a dark algal limestone, 28 ft thick, containing *Bevocastria conglobata*, *Coelosporella wetheredii*, ?*Garwoodia gregaria*, *Girvanella staminea*, *G. wetheredii* and *Ortonella furcata* (loc. 3). *Athyris concentrica*, associated with authigenic quartz, occurs in a 2-ft bed some 18 ft above the base, and *Pustula interrupta* is common on a single bedding plane, which occurs at water-level about 5 ft below the top of the limestone. In the right bank of the River White Lyne [5449 7607] the section is:

	ft
Limestone, muddy crinoidal; thin shale bands containing *A. concentrica*, *Pustula sp.* and small molluscs	11
Limestone, dark grey; prominent *A. concentrica*	5
Limestone, dark; algal layers and *Serpula advena*	12

The limestone is overlain by nearly 100 ft of shales and sandy shales which, near the mouth of Ellery Sike, are succeeded in turn by two thin limestones, the lower of which is algal. The upper limestone is affected by a small fault. In the River White Lyne this part of the sequence is largely cut out by faulting, but it includes a 6-in *Serpula* Band [5454 7604], not seen in Ellery Sike.

The sequence is continued in the right bank of the River White Lyne, downstream from the Ellery Sike confluence, by several feet of shales packed with ostracods and bivalves, and also containing *Orbiculoidea sp.* These beds are succeeded by a thick, current-bedded sandstone (for petrography see p. 211), which thins northwards, and this is followed first by shales, then by 11 ft of limestone. The lower 5 ft of the limestone are algal, with festoon structures and a typical 'nobbly top'; the upper 6 ft are cherty and shaly, with algal pellets.

Most of the overlying beds crop out in the river bed below water-level. They include a breccia, up to 1½ ft thick [5465 7562], but consist mainly of shales with thin limestone bands and with bivalves. One of a group of shaly limestones at the top of the section is believed to be the Rawney Limestone (p. 23). The sequence is terminated by faults crossing the river a few yards south of the Nixonstown footbridge.

Bothrigg Burn. The beds cropping out in the River White Lyne, downstream from the Ellery Sike confluence, are better exposed in Bothrigg Burn; the main sequence is given in Appendix I. A section of particular interest [5494 7637] in the left bank of the burn, north of Rawney Cottage is as follows:

	ft
Shales, *partly obscured*	
Limestone, banded; oolitic at top	1½
Shale	½

	ft
Limestone, flat-lying on underlying broken material; micro-fossils . .	1
Shale, disturbed	¾
Shale, calcareous; hard bands of shelly limestone; folded and broken into large blocks	2½
RAWNEY TUFF (see p. 243)	
Tuff, dark scoriaceous; small angular fragments of hard mudstone and dark limestone . .	1½
Mudstone, dark; sandwiched between two thin pale-weathering calcareous bands; all sharply contorted	2
Mudstone, calcareous yellowish striped; semi-brecciated and folded	2
Limestone, hard sandy oolitic; undisturbed	½
Shales, sandy; *partly obscured* . .	15
Sandstone, flaggy; at south end of cliff (for petrography see p. 211) . .	4

The folding of the mudstone immediately underlying the tuff may be attributable to rapid vertical loading of a saturated sediment (McKee and others 1962, pp. D153–4). The bed above the tuff may have been disturbed by earthquake movement that ceased before the flat-lying limestone with microfossils was deposited. The Rawney Tuff and associated beds were further seen in the right bank [5478 7603] south of Rawney.

The Rawney Limestone lies a short distance above the tuff. It is more than 10 ft thick and contains algal pellet and oolitic bands where seen in a low cliff in the left bank [5482 7598]. Higher beds are exposed upstream, near Hanshaw, as follows:

	ft
Shale and limestone alternations [5516 7653]	6
Limestone, grey; shale partings . .	4½
Shale	15
Limestone; shaly bands; ostracods and *Serpula sp.*	4
Shale, grey; sandy bands; some plant debris and sparse ostracods	22
Limestone; algal nodules and *S. advena*	1½
Limestone, grey impure; shale bands	8+

A short distance beyond the top of this section the stream is crossed by the New House Fault [5521 7655], which is marked by 25 ft of vertical fault-breccia. On the western side are thin limestones and dark, shelly calcareous shales dipping towards the east. About 20 yd west of the main fault is a second, subsidiary fracture, on the east side of which is an 18-in limestone, with abundant small algal pellets and larger, irregular algal growths. The beds to the west of this second fault dip steeply westwards.

Kirk Beck. In Kirk Beck the measures from the Common Flat Limestone up to the top of the Lynebank Beds are intermittently exposed. The Common Flat Limestone, 30 ft thick, with shaly bands and sparse *Spirorbis sp.*, crops out [5497 7447] immediately south of Common Flat Farm. It is overlain by limestones and calcareous shales containing bivalves, nests of *S. advena* at several horizons, and abundant ostracods. These measures end against the Bogside Fault, which cuts out 90 to 100 ft of strata, including the beds exposed at the western Banks Quarry (see below). East of the fault, the lithology is similar, but *Antiquatonia teres* is more abundant, as, for instance, in the upper part of a 22-ft limestone adjacent to the fault [5518 7441]. About 70 ft higher in the succession, and about 10 ft below the top of the Lynebank Beds, is a sandstone—the first of any significance to interrupt the shale-limestone sequence, which extends for about 1000 ft below. The petrography of the sandstone is described on p. 212. The base of the Bogside Limestone, marking the top of the Lynebank Beds, is exposed at [5554 7438]. The Kirk Beck Section is given in detail in Appendix I and shown graphically in Fig. 6.

Banks Quarry (west). The Bogside Fault lies between two large disused quarries on the hillside at Banks, a little less than half a mile north-east of Bogside Farm. The eastern quarry is in the upper part of the Bogside Limestone, but in the western quarry [5558 7490] some of the beds cut out by the fault in Kirk Beck are exposed as follows:

	ft
Shales and shaly limestone (top of north face); *Serpula sp.*, *Spirorbis sp.*, ostracods and other microfossils	4
Cementstone, shaly	3½
Cementstone, coarsely brecciated	1¼
Cementstone, finely brecciated . .	⅓
Cementstone	¾
Shale, calcareous; productid spines and microfossils	6
Limestone, shaly at top; ostracods, *Antiquatonia teres*	7

	ft
Limestone and shale in alternating bands; ostracods, crinoids, microfossils and a few *A. teres*	7

River White Lyne near Greenholme (loc. 4). South of an unnamed north-easterly fault extending between Nixonstown and Cat Scar, beds between the Rawney and Common Flat limestones are exposed in the river. They consist of shales and limestones with lithological gradations between the two. The Rawney Limestone is exposed north-east of Steppings in the left bank [5456 7509], where it is 40 ft thick and thin-bedded, with subordinate shale bands. It is also exposed in the right bank of the river [5446 7478], 50 yd N.E. of Greenholme, as follows:

	ft
Limestone, grey; sparse microfossils	6
Shale, calcareous; limestone ribs; bivalves	3
Limestone, flaggy; microfossils and two thin bands of algoolite, abundant ostracods and numerous *Serpula advena*	8
Shale, calcareous; limestone ribs; bivalves	4½
Not exposed	18
Limestone, hard massive	3

Approximately 70 ft higher in the sequence, in the left bank [5467 7512] north-east of Steppings, is a 25-ft section consisting of alternating bands of limestone and calcareous shale with a single band of rooty shale and four ochreous-weathering clay bands near the base. A band 9 ft above the base contains abundant microfossils and gastropods. Strata at about the same horizon are exposed in the left bank [5454 7485], 140 yd N.E. of Greenholme, and a short distance downstream, on the same bank, is an 18-in bed of desiccation breccia [5459 7477]. Between this locality and the Lyne Bank road bridge the sequence—interrupted by a small fault—comprises calcareous shale with subordinate limestone bands. The dip fluctuates hereabouts, but the top of the section can be seen beneath the eastern abutment of the road bridge, whence it is continued in upward succession in the Kirk Beck.

Downstream for about one mile from Lyne Bank Bridge, the river meanders in a general south-westerly direction, exposing in a series of discontinuous strike-sections, the lower part of the Upper Lynebank Beds. The Rawney Limestone, with oolitic bands crops out just downstream from the mouth of Rough Sike [5421 7394]. At Dog Pool, the river swings to a westerly course and provides good cliff sections of the beds overlying the Rawney Limestone. They consist mainly of calcareous shales and limestones with a thick desiccation breccia [5389 7336]. The Rawney Limestone, 22 ft thick and oolitic, is again exposed on both banks 40 yd E. of the mouth of Job's Cleugh [5380 9342]. Farther downstream the Cat Scar Fault and associated fractures interrupt the sequence. Adjacent to the main fault on its eastern, upthrow side is a 2½-ft bed of algoolite overlain 30 yd upstream by 15 ft of limestone, faulted at the top and with a 9-in algal pellet bed near the base. This limestone is probably the correlative of the bed cropping out 200 yd N.W. of Nixonstown. (p. 22).

The beds at Cat Scar, on the western side of the fault, form a small, faulted dome, and from there to the bend at Birk Bush the following section has been measured beneath red boulder clay:

	ft
Shale, calcareous [5354 7332]	18
Limestone, shaly; bivalves	6
Shale, platy; thin limestone bands	6
Sandstone, flaggy and sandy shale; ochreous bed at top	10
Limestone, yellow-weathering	½
Shale, sandy	3
Sandstone, flaggy	4 to 5
Limestone, ochreous-weathering; nests of *Serpula advena* and *Spirorbis sp.*	¾
Limestone, grey fine	1
Shale, limestone bands	5
Shale, sandy	5
Sandstone, massive	25
Shale and dolomitic mudstone	8
Shale and calcareous mudstone; limestone bands; *Antiquatonia teres* and *Pustula sp.* (core of dome at Cat Scar)	5

Garwood (1931, p. 106) believed the basal beds of this section to be the '*Pustula interrupta* Beds' (Ellery Sike Limestone). It seems more likely, however, that the overlying 25-ft sandstone is the correlative of the bed that crops out just downstream from the mouth of Ellery Sike, so that the beds containing *Pustula sp.* at Cat Scar are equivalent to the limestones and shales exposed near the mouth of Bothrigg Burn (p. 277).

River White Lyne, north of Wellington Gate (loc. 4). Scattered exposures of Lower Lynebank Beds in the river north of Wellington Gate include thin nodular algal limestones [5439 7655] near the axis of the Bewcastle Anticline, and an 11-ft limestone with shaly bands [5457 7667] representing the lowest limestone of Ellery Sike (p. 22). The lowest algal limestone of Ellery Sike crops out further upstream [5466 7686] where the section is:

	ft
Sandstone, flaggy	—
Not exposed	11
Limestone, grey-blue, with a band of cementstone; ostracods and *Serpula advena* at top	2
Shale, blue; bivalves	5
Limestone, dark blue; oolitic at base; sparse ostracods and small algal pellets	10
Sandstone, flaggy; shaly bands ..	19

On the western side of the anticlinal axis the Ellery Sike Limestone crops out south and north of Crook Farm. At the southern locality [5435 7706], the section is:

	ft
ELLERY SIKE LIMESTONE	
Limestone, dark blue-grey; several algal layers, ostracods at top	8
Shales and other strata	?
Not exposed	3
Shale, bluish calcareous; ostracods	1
Cementstone, dark grey ..	1
Not exposed	3
Sandstone, flaggy	2
Shales, becoming sandy towards base	3
Sandstone, flaggy; shaly at top	about 5
Shale, sandy micaceous	4
Sandstone, grey flaggy	1
Shale, grey sandy	5
Sandstone	—

At the northern outcrop [5449 7740] the Ellery Sike Limestone is at least 18 ft thick, with *Athyris concentrica* at the base and with an algal pellet bed slightly higher.

The next exposure of solid rock is three-quarters of a mile upstream [5513 7786], where a 12-ft shelly limestone is the lowest member of a section which includes a 6-ft algal and serpulid limestone [5518 7789], a bed of desiccation breccia 15 yd farther upstream, and 15 ft of shaly limestone—probably the Common Flat Limestone—containing bivalves, ostracods and gastropods [5522 7789] loc. 4g. Higher beds are exposed as far as a sharp bend in the river 60 yd upstream from the last locality.

Between the Sandcrook footbridge [5531 7825] and the mouth of Yeat Sike [5595 7911] are numerous discontinuous strike-sections in Upper Lynebank Beds, which include, east and north-east of High Onset, several algal and oolitic limestones. Small faults associated with the western extremity of the Antonstown Fault affect some of these exposures and make them difficult to interpret. In the lower reaches of Yeat Sike are still higher strata, extending up to the top of the Lynebank Beds [5611 7902].

River White Lyne, west of Lyneholmeford. West of Lyneholmeford Lynebank Beds crop out in the river only in the ground immediately west of the Lyneholmeford fault-belt where they form part of the steeply inclined western limb of the Stapleton Anticline. Exposures include a reddened limestone at least 4 ft thick cropping out adjacent to the Lyneholmeford Fault [5139 7277], whilst 30 yd downstream are 20 ft of reddened limestone believed to lie close below the Bogside Limestone.

Ashy Cleugh, Antonstown and Crew burns. Beds of Upper Lynebank age are exposed in Ashy Cleugh and Antonstown and Crew burns. They are similar in lithology to the measures described above and call for no special mention.

Bewcastle Beds

In this account the Bewcastle Beds are defined as extending from the base of the Bogside Limestone up to the base of the lowest member (Main Algal One) of the Main Algal Beds; this represents little departure from Garwood's (1931, p. 100) original definition. The total thickness of the beds, measured in Ashy Cleugh and Kirk Beck, amounts to about 600 ft (Fig. 7).

The Bewcastle Beds are more arenaceous than the underlying measures, but less fossiliferous. Sedimentary rhythms of 'Yoredale' type prevail but the sandstones are variable in thickness, and many of the limestones are dolomitic and approach 'cementstone' in lithology. Seatearths, and a single thin coal near the top of the sequence, represent the earliest terrestrial deposits within the Carboniferous of the district. Desiccation breccias are fewer than in the Lynebank Beds.

Many of the shales yield bivalves, but they are of little zonal significance. There are no corals and even crinoidal debris is sparse. Ostracods, however, are common at several horizons, and both serpulid and algoolitic bands occur, as, for instance, in the New House Limestone. Several of the sandy and non-calcareous shales contain plant material as do some of the sandstones; in Ashy Cleugh a stump of a *Lepidodendron*-like tree about 1 ft in diameter was noted *in situ*.

Algae, mostly in nodular bands, are common throughout the sequence, although they are less prominent than in the overlying Main Algal Beds. Some of the limestones can be correlated over considerable distances using the presence or absence of algae as criteria. The Rigghead and Ashy Cleugh limestones are examples in adjacent cyclothems: they are of similar lithology but the presence of algae in the former and absence or rarity in the latter serves to identify them. They are further distinguished by differences in the thin algal, oolitic or serpulid limestones underlying them, for the two thin algoolites beneath the Rigghead Limestone are separated by a bed of algal mudstone, thus making an unusual and distinctive lithological 'sandwich'. A useful marker near the top of the Bewcastle Beds is the 'Brown Band', composed of thin ferruginous shales packed with ostracods. It is of particular value in elucidating the structure around the mouth of Birky Cleugh where this part of the sequence crops out in a complex arrangement of fault-blocks (Fig. 10).

Around Bewcastle village (also named Shopford on the one-inch map) gently dipping Bewcastle Beds give rise to low-lying ground, but to the north they form the lower slopes of the fells, rising to more than 1000 ft O.D. at Grey Hill, south of Ashy Cleugh.

Nearly all of the Bewcastle Beds are exposed in Ashy Cleugh (Fig. 9) where the succession extending from the base of the Bogside Limestone up almost to the High Grains Sandstone is broken or repeated only by minor faulting. The sequence from the Bogside Limestone to the Ashy Cleugh Limestone is also exposed in the Kirk Beck west of Shopford. A further section, on the western limb of the Bewcastle Anticline, is deeply reddened at outcrop in the River White Lyne between Kaysbank and the Lyneholmeford Fault-belt. Sections through smaller parts of the sequence are exposed in Crook Burn and in a small stream (Crubinshill Sike) rising near Crubinshill Farm [507 803]; the latter includes a series of reef-like algal limestones and is interrupted by faults, which throw down parts of the overlying Main Algal Beds (Fig. 14).

BEWCASTLE BEDS: DETAILS

KERSHOPE BURN CATCHMENT

Keld Sike. Strata assigned to the Bewcastle Beds crop out in Keld Sike near English Kershope where they form part of the western limb of a syncline complementary to the north-north-easterly Routledge Burn Anticline. The fauna includes *Antiquatonia teres* (loc. 7), but is not otherwise diagnostic. An algal horizon occurs near the top of the section, which is detailed in Appendix I, p. 287.

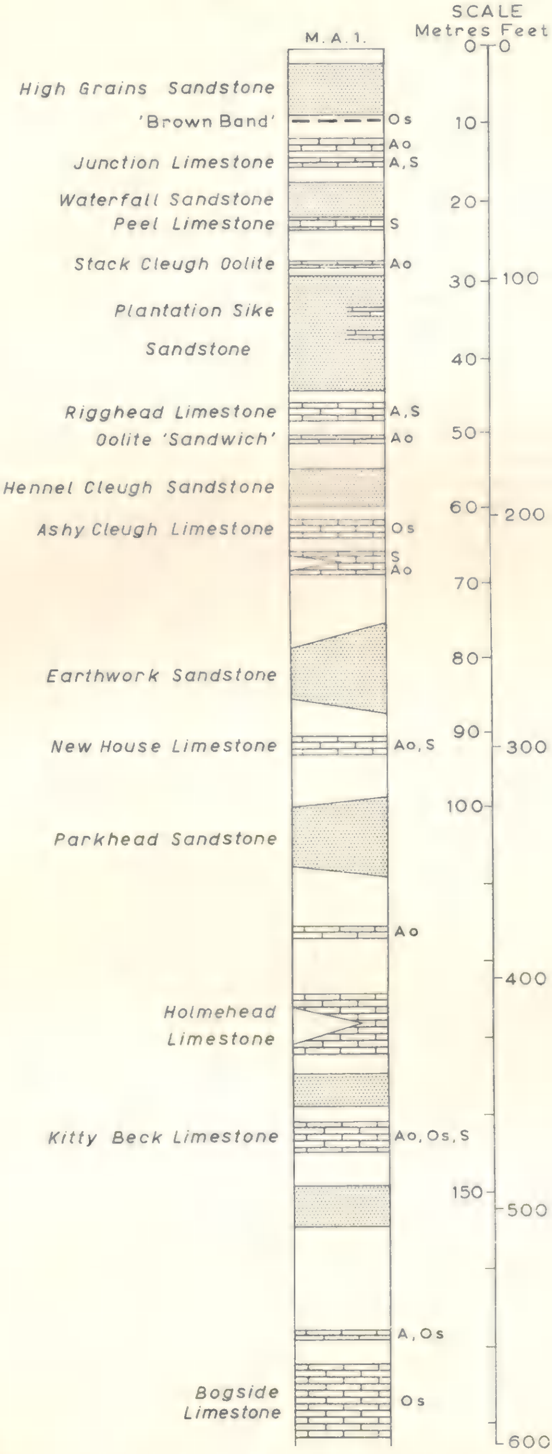


FIG. 7. *Generalized vertical section of the Bewcastle Beds. For key see Fig. 5*

About 150 yd south-south-east of English Kershope is a fine blue-grey algoolitic limestone folded into a small anticline [5266 8476]; its relationship to the previous section is obscure.

Fairies Sike. Thin limestones and shales containing indeterminate shell fragments and ostracods (including *Paraparchites sp.*) are seen in Fairies Sike (loc. 8) about a quarter of a mile north-east of Keld Sike. They lie approximately on the strike of the Keld Sike beds and are probably of about the same age.

BLACK LYNE CATCHMENT

River Black Lyne. Measures fairly high in the Bewcastle Beds crop out in the headwaters of the River Black Lyne where they are intermittently baked in proximity to the Lewisburn Dyke (p. 246). The northernmost exposures are sandstones that have been indurated in contact with the northern intrusion of the dyke (p. 246). A short distance downstream the following section is seen in the north bank [5625 8495]:

	ft
Sandstone	4
Shale	½
Sandstone	½
Shale, micaceous; plant remains	¾
Limestone	¼
Shale, blue	¾
Limestone, yellow-weathering sandy banded; geodes infilled with calcite	3
Not exposed—probably shale . .	1
Shale, calcareous; limestone ribs; yellow-weathering	1½
Cementstone, banded; yellow-weathering	1
Shale, hard blue-grey	½
Sandstone, grey	1
Shale, blue; partly baked . .	1¼
Sandstone, grey fine	3
Shale, grey flaggy micaceous . .	1

About 30 yd to south-west, 12½ ft of shales and flaggy sandstones crop out in the north bank [5622 8494] close to a small basalt dyke (p. 246), and some 50 yd downstream are the following strata:

	ft
Shale	1
Limestone, grey shaly	1
Limestone; serpulids	⅔
Shale, blue-grey	1¼
Limestone, fine-grained blue . .	⅔
Sandstone, fine-grained micaceous flaggy	2½
Shale, blue; shattered	2
Sandstone, grey fine-grained; shaly partings	2
Sandstone, grey fine-grained hard; rootlets at top	1½

The next section is seen about 100 yd downstream [5609 8487] where the following strata are folded into a monocline trending a few degrees east of north and with its axis plunging to the south:

	ft
Sandstone, shale partings	—
Shale, sandy; plant debris at top . .	4
Cementstone, decalcified . .	2
Not exposed	2
Shale, partly baked; white at top; cleaved	3
Sandstone, grey calcareous, 5 to 7 in	½
Shale, grey; shattered	1
Sandstone, grey fine-grained; plant traces; shattered, forms core of monocline	1

Beds of similar age and lithology crop out along the strike about half a mile to the south in Robbie's Grain and Shortshank Sike. The best section in Robbie's Grain is as follows [5620 8426]:

	ft
Sandstone	—
Not exposed	—
Sandstone, fine-grained; shaly partings	6
Not exposed—probably shale . .	12
Sandstone, flaggy	2
Not exposed	3½
Sandstone, hard fine-grained . .	2
Sandstone, calcareous; brown-weathering	1
Sandstone, fine-grained current-bedded	3
Not exposed—oolitic limestone debris in bank	7
Limestone, grey; brown-weathering	4½
Sandstone, fine-grained and current-bedded at top, rooty at base	4

About 50 yd downstream is a 1-ft algoolitic limestone overlying 2 ft of calcareous shale and cementstone.

About 80 yd up Shortshank Sike a thin

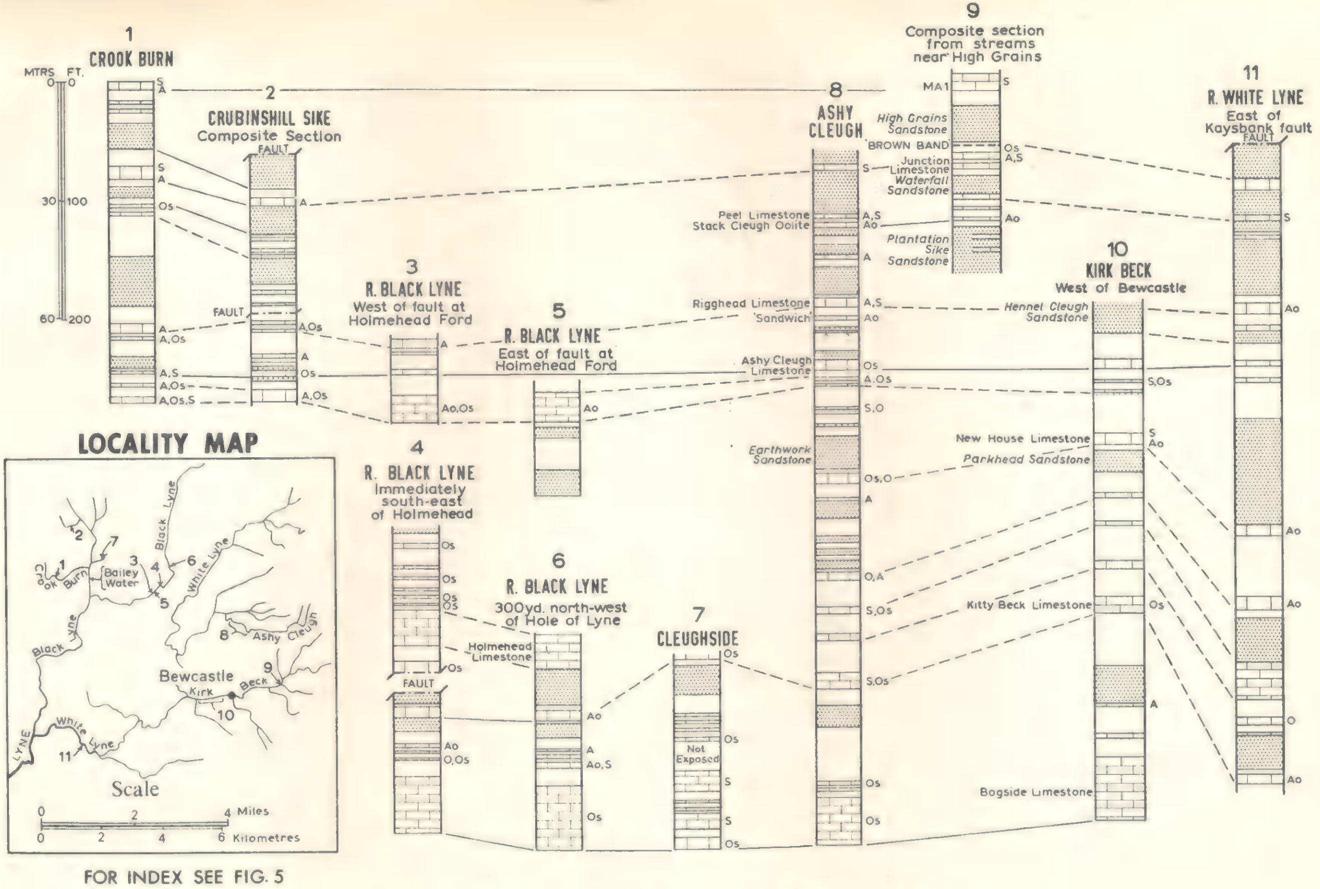


FIG. 8. *Comparative vertical sections of the Bewcastle Beds.*

algal-pellet limestone is seen. Another limestone, 1½ ft thick and apparently unfossiliferous, crops out a few yards farther upstream [5617 8403], near the Hole of Lyne Fault. It rests on 1 ft of shale and is overlain by 2½ ft of fine-grained, brown weathering sandstone which contains a fossiliferous calcareous band.

About 3 miles to the south, an almost continuous section (No. 6 in Fig. 8) through the lower part of the Bewcastle Beds is seen in the river north-west of Hole of Lyne as follows:

	ft
HOLMEHEAD LIMESTONE [5426 7896]	
Limestone, massive grey; shaly partings; *Antiquatonia teres*	20
Not exposed	10½
Sandstone, medium-grained flaggy brownish grey	20
Shale, dark	5½
Limestone, grey thinly bedded; shale partings; *A. teres*	2
KITTY BECK LIMESTONE	
Limestone, grey impure; apparently algoolitic on north bank	6½
Shale, dark grey calcareous; thin limestone bands; bivalve debris	¾
Limestone, fine grey; ostracods and shell debris	⅔
Shale, micaceous rubbly	½
Sandstone, pale grey current-bedded flaggy rooty	9½
Shale, sandy micaceous	2¾
Sandstone, flaggy	½
Shale, dark and sandy shale; limestone bands containing shell debris	7
Not exposed	2
Cementstone and shale; brecciated	3
Limestone,[1] fine dark; band of algal pellets (loc. 8a) including *Garwoodia gregaria*, *Gymnocodium sp. nov.*, *Ortonella furcata*, *O. kershopensis*	½
Shale, grey calcareous	3
Limestone, shaly	3¼
Shale, grey calcareous	4
Limestone, grey; algoolitic near base; *Serpula sp.*	2¾
Shale, grey	5½
Limestone, grey pyritous; ostracods	⅓
Shale and sandy shale, calcareous bands	4
Shale, dark grey	5½
BOGSIDE LIMESTONE	
Limestone, grey impure	¾
Limestone, fine dark grey; sparse bivalves and ostracods	5
Limestone, grey; shaly bands; abundant *A. teres*, sparse bivalves	6½
Fault, probably repeating a few feet of limestone	
Limestone, massive; in bands 9 to 10 in thick separated by thinner shaly limestones and calcareous shales; *A. teres* common throughout; sparse ostracods and bivalves	about 45
Lynebank Beds (p. 20)	—

The lower part of the Bewcastle Beds is again exposed farther downstream near Holmehead, where the dip is inverted at high angles towards the east. The sequence below the Holmehead Limestone is so similar to the above that it is sufficient to mention here only that *Girvanella ducii*, *G. wetheredii* and *G. sp. nov.* B were collected from an algoolitic band 26 ft above the top of the Bogside Limestone (loc. 9b). The sequence (No. 4 in Fig. 8) is given fully in Appendix I, p. 293.

Farther west the following short section (No. 5 in Fig. 8), is terminated west of the ford by another strike fault [5391 7814]:

	ft
Shale, dark grey; thin cementstone bands	6
Not exposed	—
Limestone, dark grey; shell debris, algoolitic nests and ostracods at top	6
Limestone, dark; part crystalline, part shaly; rare algoolitic nests containing *Garwoodia gregaria*, cf. *Gymnocodium solidum*, *Koninckopora sp.*, *Ortonella sp.* (loc. 9d)	17
Shale, dark grey; sandy at top; thin cementstone bands	6
Sandstone, pale grey medium-grained, flaggy at top, current-bedded at base	10
Shale, sandy; sandstone rib	3¼
Sandstone, pale grey	1½
Shale, grey sandy; thin bands of sandstone	22
Sandstone, medium-grained micaceous flaggy current-bedded	20

The sandstone at the base of this section is exposed immediately south-west of Holmehead Farm, where foreset beds indicate that the dip has reverted to normal.

---

[1] Garwood (1931, p. 141) obtained the paratype of *Bevocastria conglobata* from this bed.

Between the fault at the ford and the parallel large Hole of Lyne Fault is another short section (No. 3 in Fig. 8), which is exposed in the river for about 50 yd downstream as follows:

	ft
RIGGHEAD LIMESTONE	
Limestone, crystalline and calcareous shale in alternating bands; rare microfossils and *Garwoodia gregaria* (loc. 9e)	7
Limestone, crystalline and calcareous shale in alternating bands; rare microfossils and *Garwoodia gregaria* (loc. 9e)	7
Shale, grey calcareous; partly contorted; thin bands of limestone	4
Limestone, fine grey; shale bands	1
Shale, dark grey calcareous; bands of cementstone and limestone	8
Not exposed	2
Shale, dark; thin limestone partings	3
ASHY CLEUGH LIMESTONE	
Cementstone, grey; shaly at base	3
Shale, dark calcareous; limestone bands	8
Cementstone, grey flaggy	6 in to ¾
Shale, calcareous, and limestone in alternating bands; rare crinoid ossicles	3½
Shale, dark grey; thin limestone bands; indications of bedding-plane slip	3
Not exposed	up to 3
Limestone, dark grey fine to crystalline; ostracods and algoolitic horizons	12
Limestone, dark shaly; rare algoolitic pockets and ostracods	10

The thick limestone at the base of this section is sharply folded into an anticline next to the fault; a few yards downstream the dip is normal and to the west, while still farther downstream it passes through the vertical and becomes reversed.

In Crubinshill Sike (p. 33 and Fig. 8), 2½ miles N.W. of Holmehead, a thick algal limestone is developed below the Ashy Cleugh Limestone; this bed appears to represent the two thinner limestones usually present at this horizon (e.g. in Crook Burn), and is probably the correlative also of the thick algal limestone at the top of section 5 and the bottom of section 3 in Fig. 8. It follows from this correlation that the sandstone south-west of Holmehead represents the Earthwork Sandstone of the fells north of Bewcastle. It also follows that the fault inferred to pass through Holmehead Farm is small, as it shows Earthwork Sandstone on its western side against Parkhead Sandstone to the east.

Downstream from the Hole of Lyne Fault the next exposures are at a locality [5349 7774] north-north-west of Knowe Farm, where a short, incomplete sequence of sandstones and shales with subordinate limestones can probably be referred to the Bewcastle Beds. The limestones (loc. 9f) here yielded *Garwoodia gregaria*, *Girvanella ducii*, *Ortonella sp.* and fairly abundant *Serpula sp.*

Immediately south of the Bellevue Fault is an isolated exposure of algal limestone [5426 7993] which is probably a member of the Bewcastle Beds, though a Lynebank Beds age cannot be ruled out. It contains *Garwoodia gregaria*, *Girvanella ducii*, *G. wetheredii* and *Ortonella furcata* (loc. 9g).

Bailey Water. Bewcastle Beds are exposed in the Bailey Water, near Low Baileyhead, but there are better and more continuous sections in several of its tributaries. In a 500-yd stretch of the northernmost tributary, Routledge Burn, the Bogside Limestone crops out on the flanks of an anticline, the axis of which is parallel to the stream. The following section is typical:

	ft
[5195 8323]:	
Limestone, fine-grained grey rubbly; abundant *Antiquatonia teres*	3
Limestone, grey bedded crystalline black partings; crinoidal	2
Limestone, fine-grained bedded; irregular black partings	4
Limestone, fine-grained grey thinly bedded	1
[5200 8338]:	
Limestone, fine-grained grey, microfossils and worm-like markings	½
Shale, dark calcareous	1
Not exposed	2
Shale, hard dark grey; thin limestone bands	¾
Shale, dark; shell debris	1

[5209 8359]:	ft
Limestone, fine-grained grey rubbly massive; *A. teres* at top	4
Limestone, grey fine-grained shaly; brownish-weathering at base; brachiopod debris at top	3
Sandstone, medium-grained calcareous	3¾
Limestone, hard grey fine-grained crystalline	2
Limestone, hard rubbly	⅓
Limestone, fine-grained massive calcite-veined	1
Limestone, grey rubbly; *A. teres* ..	1
Limestone, fine massive	½

Almost half a mile upstream are isolated exposures of shales and thin limestones slightly higher in the sequence.

In Langley Burn measures probably referable to the Bewcastle Beds are exposed [5065 8221] 330 yd S.W. of the Corner House Inn, as follows:

	ft
Limestone, fine grey; banded ?algal structures	1
Shale, black calcareous	¼
Shale, grey; sandy at base ..	5
Limestone, blue-grey fine-grained brown-weathering	1

Another section [5074 8195] 520 yd south by west of the Corner House Inn, is:

Limestone, nodular; algal ..	1
Limestone, grey fine-grained; ostracods	2
Sandstone, medium-grained calcareous	2 to 3
Limestone, grey sandy nodular; algal	1

Steeply dipping or vertical beds of sandstone and shale with subordinate, thin ostracodal limestones are sporadically exposed between two faults 350 and 160 yd upstream from Langley Burn Bridge [5108 8067]; their position within the sequence is uncertain.

Measures folded into a syncline on the western side of Cuddy's Fault and probably belonging to the upper part of the Bewcastle Beds are exposed in the Langley Burn and the Bailey Water above and below their confluence [5162 8000]. They do not form a continuous sequence, but are given in their relative stratigraphical order:

Bailey Water [5162 8000]:	ft
Limestone, grey fine-grained crystalline; shaly partings; shell debris	1
Not exposed	8
Limestone, grey fine-grained; cementstone band	3
Not exposed	1
Shale, grey sandy	6
Cementstone	⅓
Sandstone, grey shaly	¼

Bailey Water [5161 8001]:	
?NEW HOUSE LIMESTONE	
Limestone, grey fine-grained crystalline, oolitic near base; small gastropods indet. and *Ortonella furcata*	3
Not exposed—includes some flaggy sandstone	4
Limestone, fine crystalline; *Serpula sp.* at base	5½
?PARKHEAD SANDSTONE	
Sandstone, shaly and sandy shale	5
Cementstone	¼
Shale, grey hard	1½
Sandstone; hard nodular calcareous inclusions	6
Shale, grey sandy	1
Sandstone, grey flaggy	3

Bailey Water [5161 8002]:	
Sandstone, grey flaggy	10½
Calcareous band, weathering brown; sandy and dolomitic; concentric structure	1
Shale, grey sandy micaceous ..	2
Sandstone, brown calcareous flaggy	2

Bailey Water [5162 8009]:	
Shale, grey sandy; alternating with bands of flaggy sandstone ..	4
Limestone, grey crystalline; shaly at top; thin inclusions of cementstone	¾
Shale, grey	1
Not exposed	6
Shale, grey	1
Limestone, fine grey; *Girvanella wetheredii*, *Ortonella furcata*, zaphrentid coral indet., smooth spiriferid indet., *Serpula sp.* (loc. 10)	2½
Not exposed	4
Limestone, algoolitic; dolomitic at top, algal pellets at base	1

	ft
Langley Burn [5148 8019]:	
Sandstone, grey brown-weathering micaceous; plant debris at base	4
Shale, grey sandy	6
Limestone, grey fine-grained crystalline; ?*Ortonella sp.* and *Serpula sp.* at top	4
Not exposed	3½
Shale, rubbly micaceous	6
Sandstone, grey micaceous	1
Not exposed	4
Shale, grey micaceous	2½
Limestone, fine-grained crystalline; shell debris; sparse *Serpula sp.* at top	4
Not exposed	7½
Shale, grey micaceous	1
Limestone, fine-grained crystalline; ?*Serpula sp.*	3
Shale, dark; ostracods and bivalves	1
Not exposed—probably shale	10
Sandstone, micaceous flaggy	14
Not exposed	3½
Limestone, grey brown-weathering crystalline dolomitic; rare ?*Serpula sp.*	1½

Crubinshill Sike. About ½ mile to the west, in a Langley Burn tributary which is here called Crubinshill Sike (loc. 11), is a sequence (No. 2 in Fig. 8) ranging from an algal limestone just below the Ashy Cleugh horizon up to the top of the Main Algal Beds. The lowest beds are exposed on the axis and on the western limb of the Routledge Burn Anticline, but the remainder dip steeply to east-south-east on the eastern limb. Some parts of the sequence are repeated, and others are cut out by faulting, and correlation is further complicated by a change in lithology of the algal limestones from the nodular developments of Crook Burn (pp. 36 and 47) and of the Bewcastle Fells, to the formation of '*Collenia*' growths and the investment by the various algal species of assorted organic nuclei. These algal structures at Crubinshill Sike are similar to those commonly encountered near the northern margin of the district and across the Scottish border into Roxburghshire.

Bewcastle Beds crop out in the sike in four fault-blocks. The easternmost block lies between the faults numbered 1 and 6 in Fig. 14 where the section is as follows:

	ft
Fault No. 6	
Sandstone, grey micaceous flaggy; rooty at top	9
Shale, dark grey rubbly sandy	2½
Sandstone, grey micaceous flaggy; rooty near base	19
Limestone, grey fine-grained; *Spirorbis sp.* and *Modiolus sp.*	½
Shale, dark	½
Shale, grey rooty	3
Sandstone, brownish grey micaceous flaggy; rooty at top	6
Not exposed	3
Limestone, grey; bivalves and ?*Serpula sp.*	1
Not exposed	4
Alternations of flaggy sandstone and shale	25
Not exposed	2½
Alternations of flaggy sandstone and shale	8
Sandstone, grey medium-grained; rooty at top, shale pellets at base	1
Not exposed	1¼
Limestone, fine-grained dark grey oolitic at top; *Bevocastria conglobata*, *Girvanella wetheredii*	1
Shale	1½
Sandstone, grey medium-grained flaggy	3
Alternations of grey flaggy sandstone and sandy shale	4
Fault No. 1	

The position of these strata within the Bewcastle Beds sequence is uncertain, but farther upstream, between the faults numbered 4 and 3 in Fig. 14, the uppermost part of the division can be made out as follows:

Fault No. 4	
HIGH GRAINS SANDSTONE	
Alternating bands of micaceous flaggy sandstone and sandy shale	19
Sandstone, grey-brown flaggy; shaly at base	6
Not exposed	1½
Shale, dark	2½
Shale, dark calcareous, fossiliferous	½
Limestone, impure	1
Shale, dark calcareous bands; brachiopods	3
Limestone, dark shaly; fossiliferous shale bands	4

	ft
Limestone, fine-grained dark grey algal; 'festoon' structures ('*Collenia*'-type growth-forms); *Bevocastria conglobata, Garwoodia gregaria, Girvanella sp. nov.* A, *G. nicholsoni, Ortonella furcata, O. kershopensis, O. tenuissima*	1
Sandstone, grey to green shaly flaggy; massive bands	8
Shale, dark sandy micaceous; rare plants	2¼
Limestone, blue-grey crystalline; bivalves and *Girvanella ducii*	1½
Shale, dark sandy rubbly	3
Shale, dark smooth	1
Fireclay, dark grey sandy	½
Sandstone	2
Shale, sandy micaceous; rare plant debris	5⅓
Sandstone, grey rubbly hard	1½
Shale, dark rubbly; bivalves	¼
Shale, blue sandy	4
Shale, dark; calcareous bands; bivalves and ostracods near base	3½
Limestone, grey shaly impure; crinoids and *Antiquatonia teres*	2½
Shale, dark; fossiliferous calcareous bands	6½
Alternations of grey impure limestone and calcareous shale	8
Shale, dark smooth	½
Shale, dark sandy micaceous	1¼
PLANTATION SIKE SANDSTONE	
Sandstone, grey-brown flaggy	3¼
Shale, sandy; slickensided at base	1⅓
Sandstone, flaggy	13
Shale, dark; calcareous at base	2¼
Shale, sandy	4
Sandstone, grey flaggy and shaly	4¾
Shale, grey	2
Fault No. 3	

Some of these beds are repeated upstream from Fault No. 3, where a longer succession, broken by a 16-ft fault (No. 2 in Fig. 14) continues down below the Ashy Cleugh Limestone, which crops out on both flanks of the Routledge Burn Anticline:

	ft
Fault No. 3	
Shale, dark sandy; bivalve fragments at base	8
Limestone, fine crystalline; bivalves	½
Shale, dark calcareous	¼
Shale, grey sandy; sandstone ribs	3
Sandstone; rooty at top	4
Shale, sandy dark; bivalves at base	11
Shale, dark	6
Shale, dark partly calcareous; shells	1¾
Shale, slickensided	¼
Shale, dark; fossiliferous at base	1½
Limestone, dark fine-grained crystalline; *Antiquatonia teres*	4¾
Not exposed	5
Limestone, dark grey; algal, '*Collenia*'-type growth-forms, including *Bevocastria conglobata, Girvanella sp. nov.* A, *Ortonella furcata*	¾
Not exposed	1
PLANTATION SIKE SANDSTONE	
Sandstone, grey green flaggy and massive	10
Shale, dark sandy bands; bivalves at base	13½
Not exposed	6
Shale, dark	4½
Limestone, dark fine-grained algal; *Bevocastria conglobata, Garwoodia gregaria, Girvanella ducii, Ortonella furcata, O. kershopensis, O. tenuissima* and bivalves	1¾
Shale, dark sandy	3
Not exposed	3½
Limestone, dark fine-grained crystalline; crinoids and productids	1
Fault (No. 2 in Fig. 14) cutting out strata	16
RIGGHEAD LIMESTONE	
Limestone, dark fine-grained nodular algal	2½
Shale, dark nodular; ?algal	5½
Limestone, fine-grained crystalline; *Girvanella amplifurcata, Ortonella furcata, O. kershopensis* and ostracods	1
Not exposed	9
Sandstone, micaceous	2
Not exposed	5
Shale, dark sandy; bands crowded with ostracods	3
Limestone, fine-grained crystalline; rare algal growths including *Ortonella furcata* and *O. kershopensis*, encrusting bivalves	1
Shale, dark sandy; abundant ostracods in bands	¾
Sandstone, flaggy	7½
Shale, grey sandy	4

	ft
ASHY CLEUGH LIMESTONE	
Limestone, grey crystalline; rare bivalves and ostracods	4¼
Sandstone, shaly flaggy	5½
Shale, dark sandy micaceous ..	5
Not exposed	½
Shale, grey calcareous; bivalves and ostracods	¼
Limestone, grey crystalline; bivalves and ostracods	1¼
Limestone, dark massive; bedded at top and bottom; algal nodules and growths encrusting bivalves; forms include *Bevocastria conglobata*, *Girvanella amplifurcata*, *G. ducii*, *G. nicholsoni*, *Ortonella furcata*, *O. kershopensis*, *O. tenuissima*?, *Solenopora sp.;* ostracods	9¾
Limestone, fine-grained dark crystalline; bivalves and ostracods ..	1
Shale, grey sandy micaceous ..	4½
Not exposed	4½
Sandstone, grey rubbly flaggy ..	1

Cleughside. Farther south the lowest of the Bewcastle Beds form part of a north-easterly anticline exposed in a small unnamed tributary of the Bailey Water which flows past Cleughside Farm. The Bogside Limestone lies at the core of the structure and the overlying beds crop out on the south-eastern limb upstream from Cleughside. The section (No. 7 in Fig. 8) is as follows:

	ft
Limestone, grey brown-weathering abundant ostracods at top [5198 7926]	9
Shale, with thin cementstone bands	3
Sandstone, medium-grained current-bedded flaggy	24
Shale, grey	9
Shale, poorly exposed with thin cementstone bands	7
Shale, grey calcareous; with limestone ribs [5911 7917]	2
Cementstone, grey; shaly partings	1¼
Shale, grey; thin calcareous bands; aviculopectinids	3
Cementstone, shaly; shale bands	1
Shale, grey	¾
Limestone, grey crystalline nodular; bivalves	½
Limestone, earthy	2
Cementstone, shaly nodular ..	½
Shale, grey partly calcareous; ostracods and bivalves	3
Limestone, grey fine-grained jointed; rare ostracods at base ..	1¼
Shale, grey calcareous; rare ostracods and bands containing abundant bivalves	3
Cementstone, grey	⅓
Shale, dark; beds containing abundant bivalves; ostracods at top ..	3
Not exposed	10
Limestone, fine-grained crystalline; *Spirorbis sp.*, *Serpula sp.* and ostracods	1
Not exposed ..	about 25 to 40
BOGSIDE LIMESTONE	
Limestone, grey; crystalline bands; *Antiquatonia teres*	9
Shale, grey	½
Limestone, grey crystalline crinoidal; *A. teres*	3½
Not exposed	1
Limestone, crystalline; *Serpula sp.*, *Spirorbis sp.* and ostracods ..	3
Not exposed—probably shale ..	3½
Limestone, shaly	1
Not exposed	about 5
Limestone, grey; shale partings [5187 7917]	2
Shale, dark grey calcareous ..	¾
Cementstone bands separated by shales	3
Limestone; *A. teres*	½
Shale, grey calcareous; a lens of limestone	1
Cementstone, grey	⅓
Shale, dark; bivalves	1½
Cementstone	¼
Shale, with cementstone bands ..	1
Limestone, crinoidal veined; *A. teres*	7
Limestone, grey crystalline; *Spirorbis sp.*, rare *Serpula sp.* and ostracods	5½
Shale, sandy; cementstone bands	4
Not exposed—probably shale ..	3
Shale, calcareous; ostracods ..	1
Limestone; shaly at top, crystalline at base; abundant ostracods ..	5½
Shale, *at core of anticline*	3

As it is difficult to estimate the size of the gap in the middle of this sequence, the identity of the topmost limestone is uncertain, but it is probably the Kitty Beck Limestone.

In the Crook Burn tributary, which drains the country to the west and north of the Bailey Water, there is an almost continuous sequence ranging from below the Ashy

Cleugh Limestone upwards through the Main Algal Beds into the lower part of the Cambeck Beds. The measured section is given in Appendix I, and the part relating to the Bewcastle Beds is shown graphically in Fig. 8. section 1. The succession closely resembles that of Birky Cleugh (p. 42) on the Bewcastle Fells, about 5½ miles to east-south-east.

The lowest beds, which lie just below the Ashy Cleugh Limestone, are exposed on both limbs of an anticlinal fold, the north-north-easterly axis of which crosses the burn [5025 7844] in alignment with the axes of folds exposed in Crubinshill Sike and Routledge Burn farther north. The Ashy Cleugh Limestone is thin and superficially non-algal, although rare serpulids are present and algae have been detected in thin section. The Rigghead Limestone closely resembles its counterpart in Ashy Cleugh and in the Kirk Beck, farther to the east.

WHITE LYNE CATCHMENT

River White Lyne. A section extending from the Kitty Beck Limestone nearly to the base of the Main Algal Beds is exposed in the River White Lyne between the westernmost [5140 7277] of the Lyneholmeford faults and the Kaysbank Fault [5115 7282], on the western limb of the Stapleton Anticline. The rocks are deeply reddened and the attitudes of foreset beds in the current-bedded sandstones indicate that the steeply dipping beds are not overturned. Prominent algoolitic 'pavements' are seen in the New House and Rigghead limestones, but neither the 8-ft Ashy Cleugh Limestone nor the thin limestones which underlie it appear to be algal. The sequence is shown graphically in Fig. 8 (Section 11) and in detail in Appendix I (p. 306).

Farther downstream, within the Lyneholmeford fault-belt, are a number of short, discontinuous sections in Bewcastle Beds. They include 40 ft of reddened limestone with nodular algal and algoolitic bands exposed in the river bed [5141 7276]. It is probably the Holmehead Limestone, although only 110 yd to the west that limestone is 30 ft thick and apparently non-algal. About 35 yd downstream from the 40-ft limestone, and separated from it by a small fault, the following section is seen in the right bank [5145 7276]:

?KITTY BECK LIMESTONE	
Limestone, red; bands of algoolite and *Serpula sp.*	9½
Not exposed—probably red shale	up to 10
Limestone, red	4

These beds are disturbed by two north-north-easterly fractures and another small fault.

Farther downstream, and again limited by faulting, is the following sequence:

	ft
?NEW HOUSE LIMESTONE	
Limestone, bright red; a prominent algal nodule 'pavement' and bands of algoolite; gently folded in river bed [5148 7264] ..	6
Shale and sandy shale ..	about 15
Algoolite	½
Sandstone	6

About 5 miles to north-east, the Bogside Limestone is partially exposed in the river [6507 7943], 700 yd N. of The Flatt:

	ft
Shale, calcareous bands; abundant *Antiquatonia teres*, smooth spiriferid [not collected] and crinoid stems ..	1½
Limestone, grey; bands containing abundant *A. teres*	9
Limestone, shaly; scaphopods and abundant *A. teres*	3
Not exposed—probably shale ..	7
Limestone, blue-grey; shell debris and ostracods	2
Limestone, with shaly partings; abundant *A. teres*	4

In Yeat Sike nearby, the Bogside Limestone is almost completely exposed, together with a few feet of overlying beds [5611 7902]:

	ft
Sandstone, flaggy	—
Shale, thin cementstone bands; ostracods	?
Cementstone, impure	3
Shale, dark grey calcareous; ostracods and bivalve debris	6
Shale; thin limestone and cementstone ribs; bivalves locally abundant, ostracods rare	15
Not exposed	5
Cementstone; thinly bedded; shale partings	7½

	ft
Shale, dark; beds packed with ostracods in the upper part and with bivalves in the lower ..	6¾
Limestone, dark impure; shaly partings; *A. teres*	1½
Limestone, dark hard; ostracods	1¼
Shale, calcareous; ostracods ..	1½
Cementstone, impure; shale bands; a thin limestone containing *A. teres* just above base	6
Not exposed	5
Limestone, thin-bedded; with abundant *A. teres*	1
Not exposed	4
Limestone, with shaly partings; abundant *A. teres*, rare ?*Seminula sp.*	18
Not exposed	3
Shale, dark grey; crinoid debris and productid spines	½
Limestone; abundant *A. teres* and brachiopods	3

A short distance upstream is the Kitty Beck Limestone—a dark grey bed 4 ft thick and containing ostracods [5119 7900].

Ashy Cleugh (loc. 13). An exceptionally well-exposed section through faulted Bewcastle Beds can be made out in Ashy Cleugh (Fig. 8 and Appendix I). About 38 ft of the Bogside Limestone are exposed in Stockastead Quarry [5648 7698], and the section continuing upwards in the cleugh includes 13 ft of apparently non-algal Kitty Beck Limestone and the Holmehead Limestone, which comprises two 5-ft beds separated by 18 ft of shales. The Ashy Cleugh and Rigghead limestones, exposed in a faulted complex (Fig. 9), are alike in appearance and thickness but are distinguished by differences in the lithology of the thin algal bands which lie at a similar distance beneath each of them. The band beneath the Rigghead Limestone forms a persistent 'sandwich' of:

	in
Algoolite, yellow-weathering ..	11
Mudstone, dark grey nodular algal	8 to 9
Limestone, algoolitic	10

The band beneath the Ashy Cleugh Limestone is a thin algal pellet limestone which is underlain, about 25 ft lower in the sequence, by a thin distinctive serpulid limestone. At one locality [5734 7680] the Rigghead Limestone is isolated from its underlying 'sandwich' by faults, and it is there identified by the presence of a thin inconspicuous band of pinkish algal nodules about 1½ ft from its top, for the Ashy Cleugh Limestone is nowhere seen to be algal.

The upper part of the section is also faulted. A shattered and veined serpulid limestone, seen in the bed of the stream [5765 7672] and also high in the south bank, is probably the Junction Limestone; it lies in a narrow trough bounded by sub-parallel faults trending obliquely across the stream. The base of the Main Algal Beds is represented a quarter of a mile upstream [5808 7665] by an isolated outcrop of limestone.

Antonstown Burn and Hill Cleugh. A similar, but less complete sequence, is exposed in Antonstown Burn and Hill Cleugh, nearly half a mile north of Ashy Cleugh. The section starts at the Bogside Limestone in Antonstown Burn [5655 7736], and continues about 300 yd upstream to the Kitty Beck Limestone, which is 15 ft thick and contains shale partings in the upper 10 ft and ostracods in the lower 5 ft.

The Earthwork Sandstone crops out around the mouth of Fountains Sike and in Hill Cleugh below the mouth of Harepark Cleugh. The sandstone is repeated by faulting farther up Hill Cleugh [5726 7727] where it forms part of a well-exposed sequence extending from the thin algal band below the New House Limestone up to the Plantation Sike Sandstone. The section, which is terminated by the Antonstown Fault [5765 7715], closely resembles the corresponding sequence in Ashy Cleugh.

Crew Burn. Parts of the sequence between the Ashy Cleugh Limestone and the top of the Bewcastle Beds are further exposed in Crew Burn, just over ½ mile N. of Antonstown Burn. The Bogside Limestone crops out [5622 7803] on the southern side of the Antonstown Fault, and the Ashy Cleugh Limestone is seen to be crinoidal and at least 7 ft thick on the northern side [5632 7814]. A few yards upstream two 2-ft faults traverse the following strata, which include the oolitic 'sandwich' beneath the Rigghead Limestone:

	ft
Shale	—
Limestone, algoolitic	1¼
Shale, dark grey calcareous ..	¾
Limestone, rare ooliths; algal pellets and ostracods	¾
Sandstone, flaggy	1
Shale, grey	5

The Rigghead Limestone is represented by 2 ft or more of ostracodal limestone exposed in the right bank 20 yd upstream from the 'sandwich': its outcrop, like that of the Ashy Cleugh Limestone, can be traced northwards by lines of sink-holes which stop at the western extremity of the Black Stantling Fault.

The Plantation Sike Sandstone is sporadically exposed in the burn, and the succeeding limestones are seen in the following left bank section [5643 7821]:

	ft
Limestone, yellow-weathering; *Serpula* abundant near top	5
Not exposed	3
Limestone, grey yellow-weathering; rare ostracods and shell debris	3

The immediately overlying beds, including all but a small part of the Waterfall Sandstone [5646 7825], are poorly exposed, but the highest of the Bewcastle Beds are seen farther upstream [5687 7838] as follows:

	ft
Main Algal Beds (p. 281)	—
Not exposed—probably shale	10
Sandstone, fine-grained, shale partings	3
Mudstone, brownish grey, micaceous	2½
Shale, dark grey; abundant plant debris	1½
Mudstone, grey, planty	3
Nodular ferruginous band; plant debris	up to ½
Shale, grey, micaceous	⅓
HIGH GRAINS SANDSTONE	
Sandstone, fine-grained jointed	1½

Between Ashy Cleugh and Kirk Beck. On the high ground south of Ashy Cleugh alternate hard and soft bands in the Bewcastle Beds form easily traced features, the crops of limestones being marked by lines of sink-holes. Several faults traverse the area, among them the New House Fault which repeats the Parkhead and Earthwork sandstones near Crossgreens and New House; both sandstones have been quarried hereabouts. The Bogside Limestone has been quarried [5641 7652] in Dobby's Sike, but only 8 ft of limestone with abundant *Antiquatonia teres* can now be seen. The limestone was also worked in the Old (east) Quarry [5566 7481] at Bewcastle Banks where the section is:

	ft
Shale	1
Cementstone, shaly	2¾
Shale; microfossils	1⅓
Shale and cementstone in alternating bands; shell debris and microfossils	3½
Shale, dark; abundant ostracods	6
Limestone, grey; shaly at base; abundant *A. teres* at top	5
Shale, dark; limestone ribs; abundant *A. teres*	8 to 9
BOGSIDE LIMESTONE	
Limestone, grey massive; thin shale bands	10
Not exposed—probably shale	6 to 7
Limestone, shaly	4

The New House Limestone was formerly excavated along its outcrop on the high ground between New House and Peel O'Hill Farm, but only 2 ft of algoolite are now exposed [5603 7562].

The lower part of the Plantation Sike Sandstone together with about 28 ft of underlying beds crop out in Bride's Gill where the sandstone forms a gentle syncline. The section [5656 7530] is:

	ft
PLANTATION SIKE SANDSTONE	
Sandstone, fine-grained current-bedded massive	6+
Shale, sandy	6
Shale, dark; fireclay bands	3
Shale, dark sandy	3 to 5
Shale, light grey sandy	1
Shale, calcareous; limestone lens containing rare ?algal nodules	3
Shale, sandy; calcareous nodules	8
Sandstone	1
Shale, sandy	3

Kirk Beck: west of Bewcastle. The Kirk Beck section (Fig. 8 and Appendix I) starts in Lynebank Beds (p. 288) and continues through the Hennel Cleugh Sandstone [5629 7445], the petrography of which is described on p. 212. The Bogside Limestone [5558 7438] is 52 ft thick. The Kitty Beck Limestone, 15 ft thick and apparently non-algal, is exposed for 150 yd along the strike [5595 7445], and the New House Limestone, about 10 ft thick including thin serpulid and algoolitic bands, crops out at a sharp bend [5620 7453], 340 yd downstream from Bewcastle. The Ashy Cleugh Limestone [5624 7450] is 5 to 6 ft thick and contains

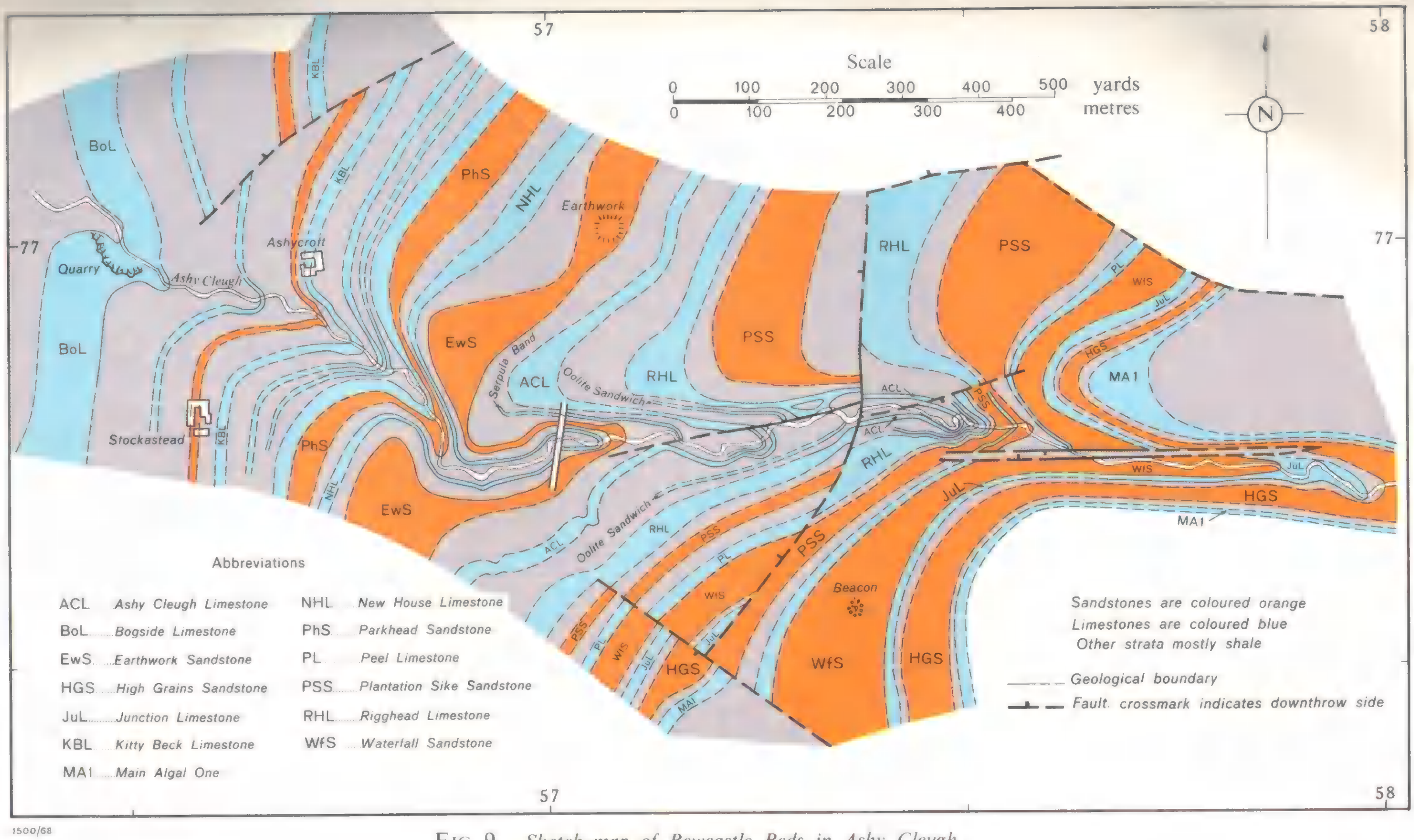


FIG. 9. *Sketch-map of Bewcastle Beds in Ashy Cleugh*

bands of cementstone. The Rigghead Limestone is not exposed in this part of the beck; it may be partly represented by 1 ft of algal limestone cropping out in the bank on the north side of the road [5648 7452], although it is possible that this rock is not *in situ*. According to Garwood (1931, pp. 108–9) "nearly half a mile west of Bewcastle Bridge where the stream [Kirk Beck] makes a sharp bend to the south" there is a thin algal band containing *Ortonella furcata* which is "crushed against the east side of the [Pennine] fault and is traversed by calcite veins". During the resurvey, a bed of limestone 2 to 3 ft thick, containing alga-encrusted bivalves, was seen [5573 7443] beneath nearly 30 ft of sandstone, but no trace of faulting was found; the Bogside Fault, possibly representing part of the northerly extension of the Pennine Fault-system, crosses the stream 650 yd W. of this locality.

Kitty Beck. Kirk Beck is joined near Bogside Farm by the tributary Kitty Beck, in which are discontinuous exposures of sandstone and shale, as well as part of the Kitty Beck Limestone seen at the top of the following section [5559 7375]:

	ft
Limestone, grey shaly nodular algal	2
Shale, grey; limestone ribs	3 to 4
Sandstone, pale grey, slightly calcareous	1

Of this exposure Garwood (op. cit.) stated "here, again, it occurs close to the east side of the [Pennine] fault". However, no evidence of faulting was found nearby during the resurvey, and it seems possible that Garwood may have confused this horizon with an inconspicuous algal layer more than 70 ft below the Kitty Beck Limestone in Kirk Beck, or with the Rigghead Limestone at Rigghead Barn, about 250 ft higher in the sequence.

About a quarter of a mile upstream, the Hennel Cleugh Sandstone is at least 15 ft thick and is fine-grained, white and massive. At Fawcettlees Farm the Plantation Sike Sandstone [5640 7354] is represented by 6 ft of fine-grained flaggy sandstone, resting on 2 ft of grey sandy shale. The highest bed exposed [5663 7351] is a 1-ft shaly cementstone.

Kirk Beck and tributaries: east of Bewcastle. In the eastern part of Kirk Beck and the tributaries Bull, Birky and Stack cleughs and Green's Burn, the upper part of the Bewcastle Beds shows considerable lateral variation. The sequences seen in these streams range upwards through the main Algal Beds into the lower part of the Cambeck Beds: they are detailed in Appendix I. The disposition of the Bewcastle Beds of this area is shown in Fig. 10,[1] and sequences are shown graphically in Fig. 11.

The Kirk Beck east of Bewcastle is known under a variety of names. It is called Hennel Cleugh between the mouth of Green's Burn [5760 7482] and Birky Cleugh [5837 7512]; farther north it is referred to throughout this memoir as Bull Cleugh. An unnamed northern tributary, which enters Hennel Cleugh [5829 7505] 100 yd S.W. of Birky Cleugh, is here called Plantation Sike: it gives its name to the sandstone which crops out around the junction of the two streams.

The Shopford Fault crosses Kirk Beck a few yards east of the bridge at Bewcastle; the Hennel Cleugh Sandstone is repeated on its eastern (upthrow) side, and a short distance upstream on the right bank [5723 7479] the base of the Rigghead Limestone is seen as follows:

		ft
RIGGHEAD LIMESTONE		
Cementstone, banded		6 to 7
Shale, dark calcareous; poorly exposed		2 to 3
Limestone; rare serpulids and microfossils	'Sandwich' of Ashy Cleugh	1
Shale; abundant marble-sized algal nodules		¼
Limestone, algal at top		1 to 2

This section is terminated by the New House Fault [5728 7480] on the eastern side of which the crop of the Hennel Cleugh Sandstone, forming a waterfall, is again repeated. It is also seen a few yards to the east where it forms a small outlier at the centre of a minor syncline. Upstream from this locality to the next major fault [5824 7499], strata up to the Rigghead Limestone are disposed in a gentle anticline. The Earthwork Sandstone, at the core, is exposed on both sides of the mouth of Green's Burn [5759 7482]. The complete sequence is best seen in the lower part of Green's Burn as follows:

---

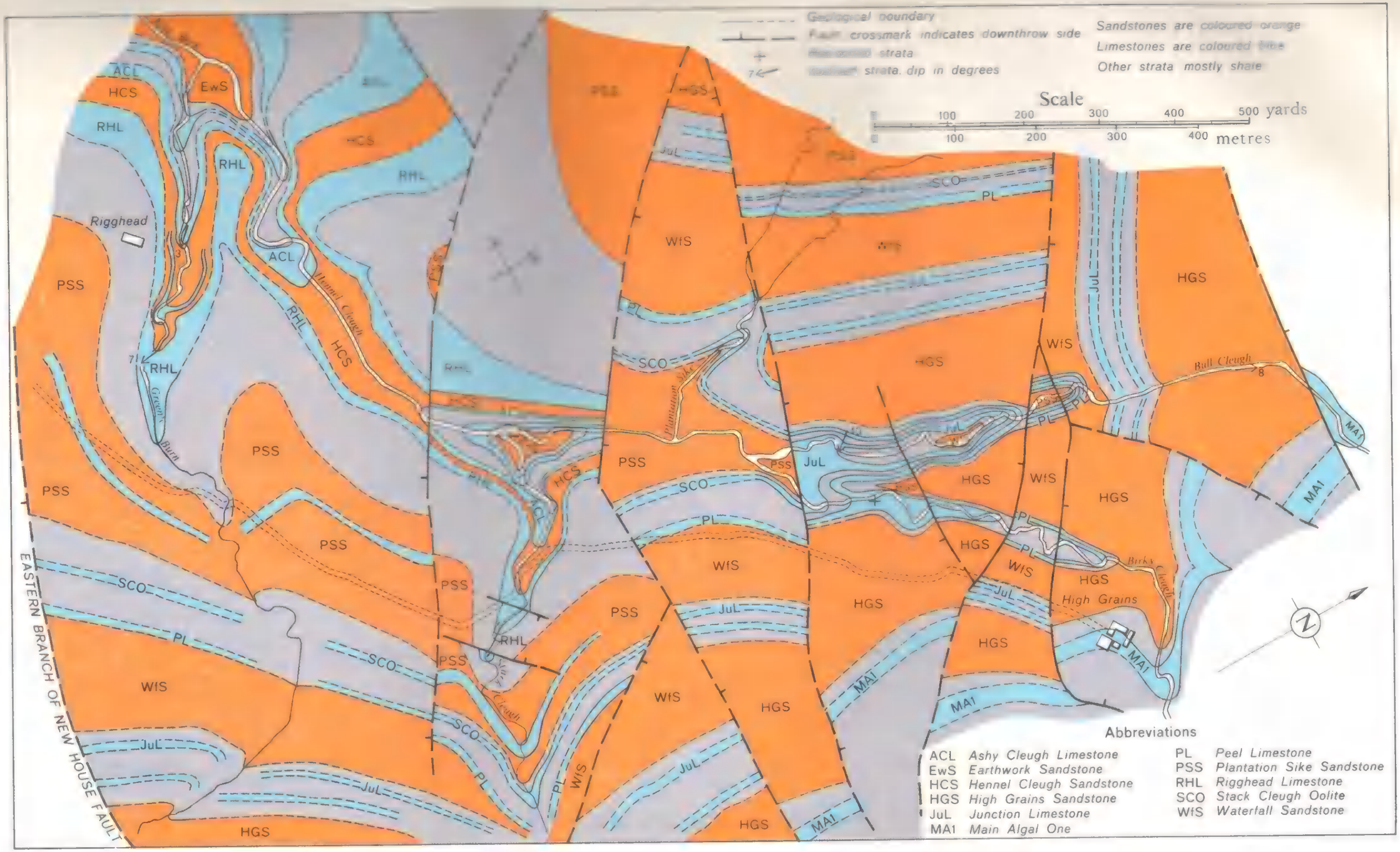
[1] Grid line numbered '76' on Fig. 10 should read '75'.

		ft
PLANTATION SIKE SANDSTONE		
Sandstone, massive; exposed a few yards upstream from the ford		—
Not exposed		4
Shale, very sandy; sandstone band [5797 7453]		15
RIGGHEAD LIMESTONE		
Cementstone, unfossiliferous		4 to 5
Algal breccia; serpulids, *Girvanella ducii* and *G. staminea* (loc. 14a)		1¼
Cementstone, banded; rare *Spirorbis sp.*		7
Shale, grey		5
Cementstone, shaly; barren ..		3
Limestone; sparse algae		½
Algal breccia ..	1 in	—
Limestone, algal; *Girvanella ducii*, *G. amplifurcata*, *G. magna*, *Ortonella furcata* and *O. kershopensis* (loc. 14b)		¾
Limestone, fine-grained; unfossiliferous		½
HENNEL CLEUGH SANDSTONE		
Sandstone, massive		5
Shale, sandy		2½
Sandstone, massive		8
Mudstone, grey shaly; unfossiliferous		8
ASHY CLEUGH LIMESTONE		
Cementstone, banded; unfossiliferous		8
Mudstone, grey shaly		7½
Limestone; nests of microfossils ..		1½
Shale, limestone ribs		2
Limestone		2
Shale; brecciated at top, including more finely graded material below [5764 7477]		4⅔
Not exposed		4 to 5
EARTHWORK SANDSTONE		
Sandstone, massive current-bedded		12

In Hennel Cleugh, 180 yd upstream from the mouth of Green's Burn, 6 to 7 ft of shales immediately underneath the Ashy Cleugh Limestone include a thin bed of desiccation breccia. Around the mouth of Stack Cleugh [5818 7488] and upstream of a 6-ft fault [5811 7481] with a southerly downthrow is a second, gentle anticline with the Earthwork Sandstone exposed at the core. In the lower part of Stack Cleugh, below the ford [5834 7479] the sequence is similar to that in the lower part of Green's Burn, both Ashy Cleugh and Rigghead limestones being represented; above the ford a long section extends upwards into the Main Algal Beds (Appendix I, pp. 315–6). In this section the Plantation Sike Sandstone, more than 30 ft thick, includes two limestones (cf. White Beck) the lower of which overlies 3 in of shaly coal—the lowest recorded coal of the Carboniferous succession in the district. A few feet higher in the sequence is the Stack Cleugh Oolite—a valuable local marker band which takes its name from this locality. Another useful marker, here called the 'Brown Band', occurs below the High Grains Sandstone; it consists of a few inches of ferruginous shale, containing abundant ostracods.

The sequence in the upper part of the Bewcastle Beds, which crop out in the remainder of Hennel Cleugh (that is upstream from the mouth of Stack Cleugh), and in the lower reaches of Bull Cleugh and Birky Cleugh, is broken by a number of small north-westerly faults. Around the mouth of Plantation Sike the sandstone of that name is upwards of 35 ft thick, but neither of the limestones included in it at Stack Cleugh and White Beck (pp. 40–42) is seen. A few inches of the sandstone contain numerous worm-borings [5830 7509]. About 150 yd up the sike [5823 7517] is the Stack Cleugh Oolite, represented by 5 in of serpulid and algoolitic limestone resting on 1 ft of slightly sandy, nodular algal mudstone and overlain by 4 in of ochreous decalcification breccia. The bed is repeated by faulting farther upstream, in the easterly tributary of the sike, where it comprises 8 in of hard, flaggy algoolite [5816 7541].

Another fault, crossing Bull and Birky cleughs, less than 100 yd upstream from their confluence, throws down higher beds to the north against the Plantation Sike Sandstone or the overlying Stack Cleugh Oolite to the south. The higher beds, which lie between the High Grains and Waterfall sandstones, form a trough bounded to the north by a west-north-westerly fault. A generalized sequence follows:



1500/68

FIG.10. *Sketch-map of Bewcastle Beds in the Rigghead–High Grains area*

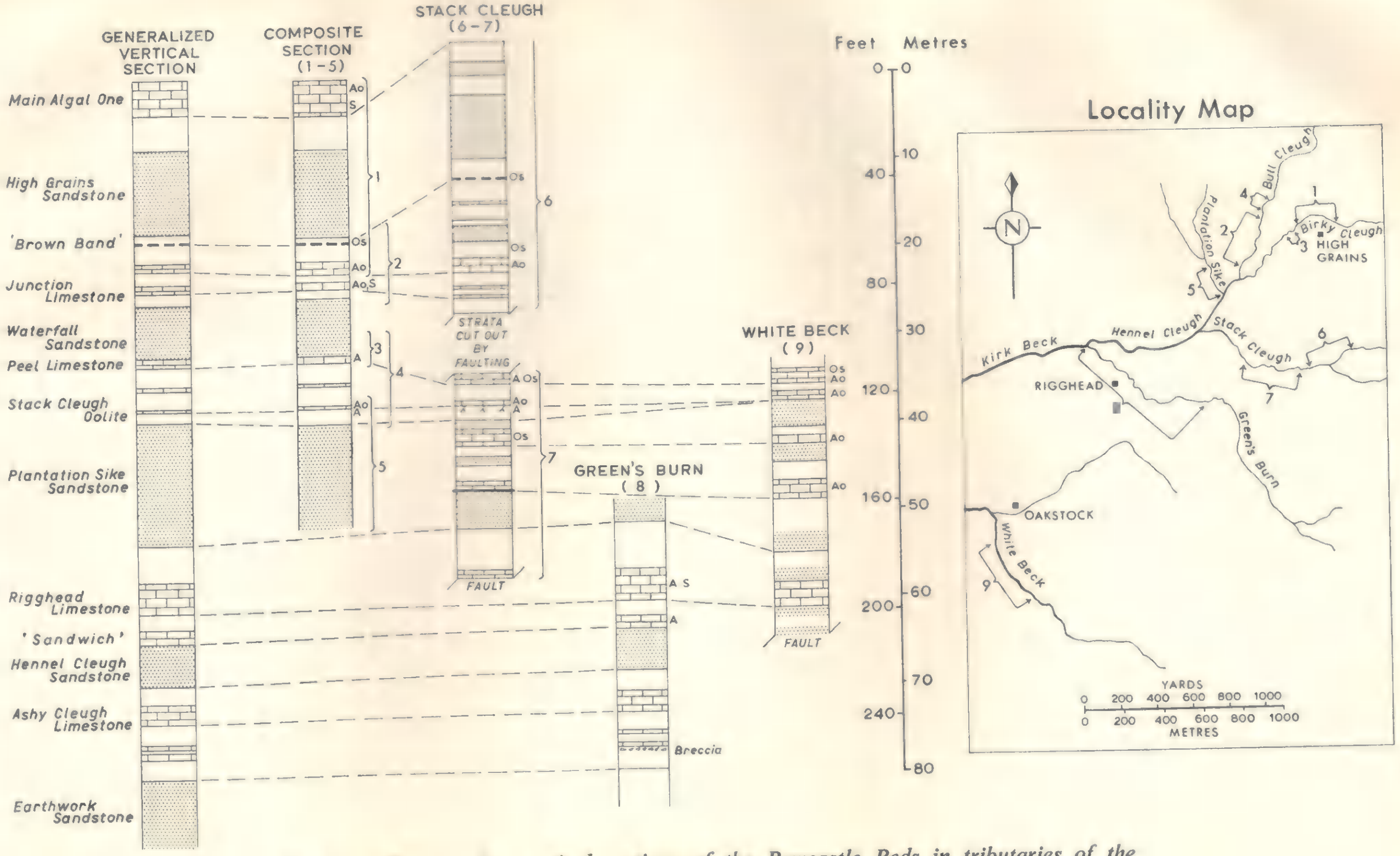


FIG. 11. *Comparative vertical sections of the Bewcastle Beds in tributaries of the Kirk Beck, east of Bewcastle. For key see Fig. 5*

	ft
HIGH GRAINS SANDSTONE	
Sandstone, massive medium-grained	6
Shale; thin calcareous bands at base; the 'Brown Band' crops out [5851 7543] in Bull Cleugh immediately south of the fault	6
Cementstone; a band of inconspicuous algal nodules 1¾ ft above base [Birky Cleugh 5849 7522]; *Serpula sp.* associated with nests of algoolite in a flaggy band near top	2¼
Shale, sandy	3 to 5
JUNCTION LIMESTONE	
Limestone, algoolitic; *Serpula sp.* and *Spirorbis sp.*	¼
Cementstone; unfossiliferous ..	2
Shale; dark pyritous; fish scales and *Lingula sp.*	3
Not exposed	1 to 2
WATERFALL SANDSTONE	
Sandstone, massive [5848 7535]	3

North of the trough is a narrow horst formed in Bull Cleugh [5851 7551] by the following beds:

	ft
WATERFALL SANDSTONE	
Sandstone, massive current-bedded medium-grained; forming grotto and waterfall ..	20
PEEL LIMESTONE	
Limestone, grey yellow-weathering hard massive; bands of algal breccia	3
Shale, grey; thin limestone ribs	7
Cementstone, unfossiliferous ..	1¼
Mudstone, dark grey shaly ..	7
Decalcification breccia, ochreous	⅔
STACK CLEUGH OOLITE	
Limestone, algoolitic; serpulids	½
Mudstone, sandy; small algal nodules	1½
Mudstone, pale grey sandy ..	2¾
PLANTATION SIKE SANDSTONE	
Sandstone, massive medium-grained	2

In Birky Cleugh, within the same horst, the Peel Limestone is exposed in the left bank [5866 7536] opposite the ruins of the old peel tower; it consists of 2 ft of algal breccia and is directly overlain by the Waterfall Sandstone.

Beds between the Waterfall and High Grains sandstones are not exposed in Bull Cleugh above the grotto, but in Birky Cleugh the full sequence from just above the top of the Junction Limestone to the base of the Main Algal Beds can be made out (Appendix I, pp. 272–5) between the fault at the peel tower [5865 7538] and the ford immediately north of High Grains. The 'Brown Band' of Stack Cleugh (p. 40) is exposed [5870 7539] in the left bank; it consists of two thin bands of ferruginous shale which contain abundant hematitized ostracods and which are separated by 6 in of non-ferruginous grey shale. The overlying High Grains Sandstone is massive, current-bedded, medium-grained and whitish, and is 35 ft thick. It is capped by about 15 ft of shale at the ford.

An unnamed streamlet east of Low Grains Farm is crossed by a north-north-westerly fault [5777 7520] which gives rise to nearby springs associated with considerable deposits of calcareous tufa. On the western, upthrow, side of the fault is a short sequence commencing with the New House Limestone [5774 7515] which contains *Garwoodia gregaria* and *Girvanella ducii* (loc. 15) and ranges up through the Earthwork Sandstone to a shattered limestone at the fault. The latter is 5 to 6 ft thick and lies a few feet above the top of the Earthwork Sandstone; it presumably represents one of the thin limestones beneath the Ashy Cleugh Limestone in Kirk Beck and Ashy Cleugh (Fig. 8). The fault cuts out the Ashy Cleugh and Rigghead limestones, and on the north-eastern, downthrow, side the Plantation Sike Sandstone is exposed in the stream for about 200 yd. It is followed closely by the overlying Stack Cleugh Oolite, the outcrop of which is marked by the debris of hard, yellow-weathering algoolite in a small tributary [5773 7541].

White Beck. Measures between the top of the Hennel Cleugh Sandstone and the Peel Limestone are exposed in White Beck. As in Stack Cleugh (p. 40, Fig. 11), the normally thick and massive Plantation Sike Sandstone includes algoolitic limestone and shale. The Rigghead Limestone, at least 8 ft thick, is particularly well exposed for some distance along the strike, south-west of Oakstock. The section is as follows:

	ft
PEEL LIMESTONE	
Limestone, fine dark compact; abundant ostracods and microfossils [5723 7362]	2
Limestone, impure; rare algal nodules and ooliths	4 to 4½
Shale and mudstone, limestone ribs	2
Limestone, impure; slightly sandy	2½
STACK CLEUGH OOLITE	
Algoolite, sandy	½
PLANTATION SIKE SANDSTONE (for petrography see p. 212)	
Sandstone, massive; forming waterfall	9
Mudstone, grey shaly	3
Limestone, impure muddy	2
Algoolite	¾
Mudstone, calcareous	½
Sandstone, massive	6
Mudstone, shaly	7
Limestone, impure	2
Algoolite	1¼
Limestone, shaly	2⅔
Limestone, hard sandy	½
Not exposed	about 12
Sandstone	2
Not exposed	about 12
Sandstone, flaggy and sandy shale	6 to 7
RIGGHEAD LIMESTONE	
Cementstone, banded; unfossiliferous	10
Sandstone	2
Not exposed	4
Sandstone	2
Fault	

The Stack Cleugh Oolite [5784 8424] is exposed between two branches of the New House Fault in a small tributary which joins White Beck at Oakstock. It consists of 5 in of hard sandy ferruginous algoolite with well-rounded ooliths, resting on 1 ft of grey sandy shale and 2 ft or more of flaggy sandstone.

About 40 yd upstream 6 in of hard, sandy, limestone probably represents the overlying Peel Limestone. This limestone is further exposed [5768 7428], 2 to 3 ft thick, beyond the southern branch of the New House Fault; it is underlain 70 yd farther downstream by 2 ft of nodular algal limestone believed to lie immediately above the Stack Cleugh Oolite (cf. the White Beck section) which is not itself exposed.

MAIN ALGAL BEDS

The Main Algal Beds include at least fourteen distinctive algal, algoolitic or serpulid bands or groups of bands, numbered in upward sequence, and for convenience referred to throughout this account in abbreviated form M.A.1 to M.A.14. The succession is shown graphically in Fig. 12. The definition of the Main Algal Beds here adopted conforms with that of Garwood's (1931, p. 100) 'Main Algal Series', extending upwards from the base of M.A.1 (the '*Serpula* cf. *advena* Band' of Garwood) to the top of M.A.14 (equivalent to the base of Garwood's Upper '*Dictyoclostus*' *teres* Band).

Lithologically the Main Algal Beds are disposed in rhythmic alternations—mainly of limestone and shale—differing from the measures above and below mainly in the number of well-developed algal horizons. The algae occur mostly as nodules in limestones or shales, but they are found rarely in sandy shales and at one locality in sandstone. Individual limestones are commonly 3 to 12 ft thick, but the Birky Cleugh Limestone, which includes M.A.5 and M.A.6 separated by a shelly massive limestone, attains a total thickness of about 20 ft.

M.A.1 generally comprises a thick serpulid reef overlain by several feet of oolitic cementstone associated with small '*Osagia*'-type algal nodules. Another serpulid reef forms M.A.3. A thick band of conspicuous, graded algoolite occurs near the base of M.A.8 and probably represents the 3-in oolite band referred to by Garwood (op. cit., pp. 110–1).

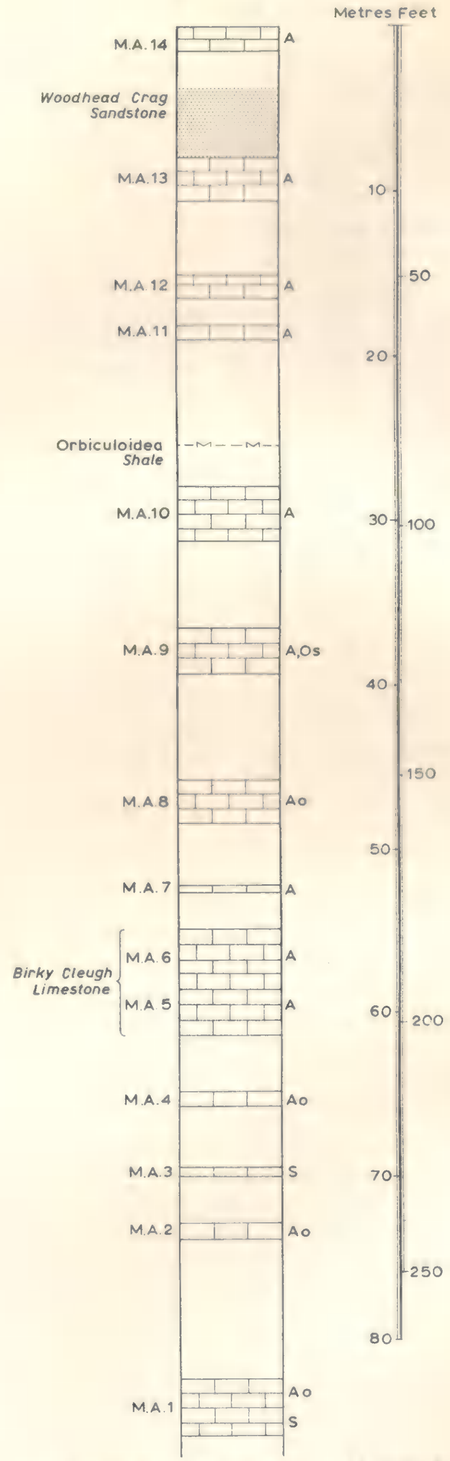
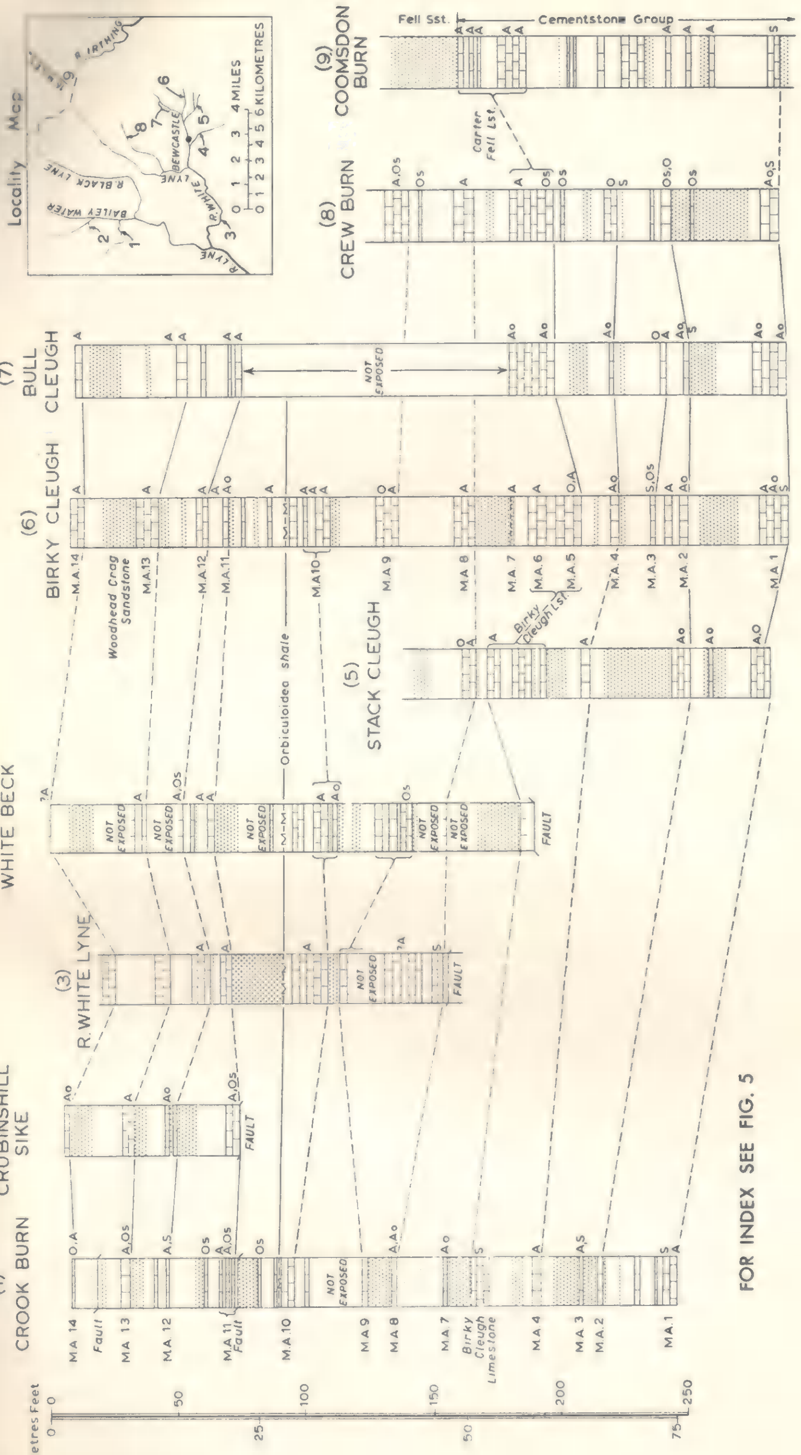


FIG. 12. *Generalized vertical section of the Main Algal Beds. For key see Fig. 5*



FOR INDEX SEE FIG. 5

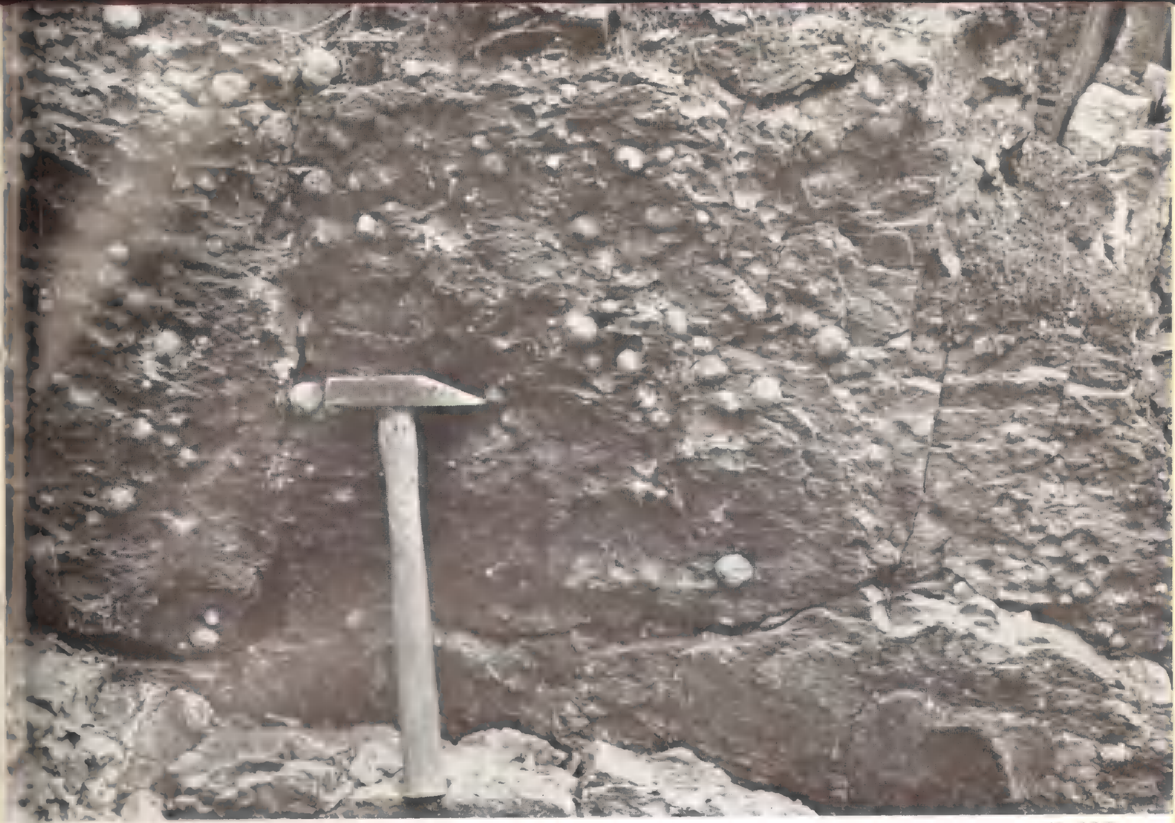
FIG. 13. *Comparative vertical sections of the Main Algal Beds*

The *Orbiculoidea* Shale (op. cit. pp. 110, 112) forms a useful marker band within the district, and has also been found across the Scottish border in the Tweeden Burn at Black Pool. In addition to various species of *Orbiculoidea*, these shales contain bivalves including abundant *Sanguinolites sp.* About 25 ft higher in the sequence lies M.A.12, believed to be the equivalent of Garwood's 'Main Reef'. This term is not used in this account because in the type section—Birky Cleugh—it is a nodular limestone far less like a 'Main Reef' than some of the massive '*Collenia*'-type algal developments which occur at other horizons to north-west apparently in the direction of the contemporaneous shore-line. M.A.13 is lithologically similar to M.A.12 and is overlain by the persistent Woodhead Crag Sandstone—a forerunner of the contorted current-bedded sandstones which are typical of the Middle Border Group and the Northumbrian Fell Sandstones to the north-east.

A complete sequence measuring about 285 ft through the Main Algal Beds is exposed in Birky Cleugh, a tributary of the Kirk Beck. Parts of the sequence are also exposed nearby in the sub-parallel Bull and Stack cleughs, and in White Beck. In the River White Lyne north-east of Kaysbank there is a continuous sequence from M.A.8 up to the top of the beds, but dips are steep or vertical and the measures deeply reddened. Other reddened measures near the top of the Main Algal Beds crop in the Kirk Burn at Stapleton. In the western part of the district a complete sequence, very similar to that in Birky Cleugh, is present in Crook Burn, and the measures above M.A.11 dip at high angles or are inverted in association with faulted Bewcastle Beds in 'Crubinshill Sike' (Fig. 14). Short faulted sequences are also exposed in Cuddy's Burn nearby.

The Main Algal Beds can be recognized to the north in streams draining the Larriston Fells (Scottish Sheet 11). Partial sequences are exposed in the Harden, Larriston and Piper burns and a more complete sequence is seen in Tweeden Burn (Lumsden and others 1967, pp. 83–7) where the lithology and thickness are similar to the type section in Birky Cleugh, 9 miles to the south-east.

About 20 miles north-east of Bewcastle, algal measures are exposed in several streams, one of which, Coomsdon Burn, drains the Carter Fell area at the head of Redesdale (English Sheet 8, Elsdon). Garwood (1931, p. 135) equated these measures with the algal bands of Cambeck age at Kershopefoot, but Anderson (1950, pp. 16–9) preferred to correlate them with the Main Algal Beds of Bewcastle, although he believed there was "no exact correspondence between the two". More recent measurement of the Coomsdon Burn sequence (Appendix I, Fig. 13) shows its close resemblance to the lower part of the Main Algal Beds of the Bewcastle district, and in particular, it establishes a correlation between the Carter Fell and Birky Cleugh limestones. Because the Carter Fell Limestone is immediately overlain by local 'Fell Sandstone' it follows that in Redesdale the measures equivalent to the upper half of the Main Algal Beds and the whole of the Cambeck Beds are either cut out by unconformity (there is a thin conglomerate at the base of the Fell Sandstone) or, more probably, are absent because of a gradual change in facies brought about by interdigitation of sandstones from the north-west. Similar evidence can be cited from the Rothbury district (Garwood 1931, pp. 135–6) where beds of Main Algal type, lying at the top of the 'Cementstone Group', are directly overlain by 'Fell Sandstone' with no sign of intervening Cambeck Beds.



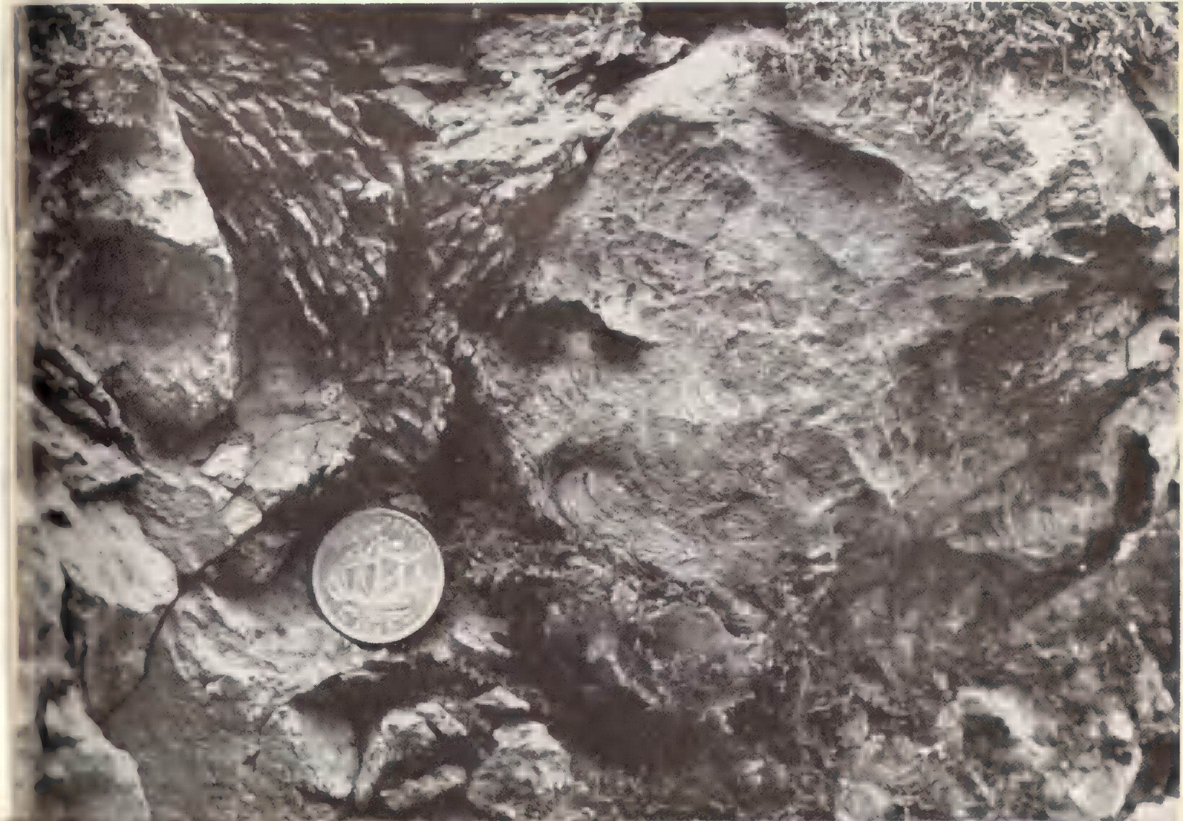
(L 466)

A. ALGAL NODULE BED WITH '*OTTONOSIA*'-TYPE GROWTH-FORMS; MAIN ALGAL ELEVEN, RIVER WHITE LYNE

PLATE II

B. ALGAL COLONY WITH '*COLLENIA*'-TYPE GROWTH-FORMS; MAIN ALGAL ELEVEN, RIVER WHITE LYNE

(L 467)



LYNE CATCHMENT

Kirk Burn. In Kirk Burn (not to be confused with Kirk Beck, which flows through Bewcastle village) Main Algal Beds are exposed immediately south of Stapleton church, where they form part of the eastern limb of the Stapleton Anticline. The beds are reddened and dip at moderate angles to the south-east; the attitude of '*Collenia*'-type algal growth forms in some of the limestones shows this dip to be normal, in contrast to the reversed south-easterly dips of the Main Algal Beds in the River White Lyne, 1¼ miles along the strike to the north-north-east.

The lowest bed [5031 7111] consists of 7 ft of calcareous sandstone with orthocone nautiloids; this is successively overlain, after an unexposed interval, by a thin red limestone, by 4 ft of red limestone with gastropods, and by two 15-ft red shaly limestones [5036 7111]. Next in upward succession are several feet of pinkish sandstone overlain by 9 ft of red marls with nodules (loc. 16a) containing *Girvanella amplifurcata* and *Ortonella furcata*. Cropping out above them, 35 yd west of the footbridge, are marls and marly red limestone containing large compound algal masses with good '*Collenia*'-type forms still in positions of growth. The nuclei of these masses are commonly orthocone nautiloids, and the algal species include *Bevocastria conglobata*, *Garwoodia gregaria*, *Girvanella sp. nov.* A, *Ortonella furcata* and *O. kershopensis* (loc. 16b). This is probably the M.A.12 horizon of Birky Cleugh (p. 61); the overlying M.A.13 is represented by 3 ft of red algal limestone which crops out in the right bank immediately west of the footbridge, and which yielded (loc. 16c) a specimen of an orthocone nautiloid thickly encrusted with *Girvanella ducii*, *G. nicholsoni* and *Ortonella furcata*.

BLACK LYNE CATCHMENT

Crook Burn. (loc. 17). This section, which starts in the underlying Bewcastle Beds (p. 35) and extends up into the overlying Cambeck Beds (p. 72), is the best exposed and most complete sequence through the Main Algal beds in the Black Lyne Catchment. It is detailed in Appendix I (p. 283) and is shown graphically in Fig. 13 (section 1) which brings out the close resemblance to the type section in Birky Cleugh (p. 60).

The basal limestone (M.A.1) is 5 ft thick [5040 7841] and contains scattered *Serpula sp.* M.A.4 consists of 2½ ft of shelly limestone, with a nodular algal top. The overlying Birky Cleugh Limestone is crowded with *Serpula sp.*, but is only 7 ft thick (its base is not exposed) as compared with about 20 ft in Birky Cleugh. M.A.7 and M.A.8 are thin algoolitic limestones, and M.A.10, exposed in the right bank [5052 7840] is immediately overlain by calcareous shales containing *Sanguinolites sp.* and *Orbiculoidea nitida*—the '*Orbiculoidea* Shale' of Birky Cleugh. M.A.11, M.A.12 and M.A.13, exposed between two minor faults, are represented by thin nodular, algal limestones, two of which are associated with thin non-algal limestones. M.A.14 consists of 1 ft of nodular algal and algoolitic limestone cropping out [5060 7846] on the eastern side of the two faults and again downstream in the left bank of a sharp bend [5068 7855].

Crubinshill Sike. Because of faulting, only the highest measures (M.A.11 to M.A.14) crop out in Crubinshill Sike (Fig. 14). They resemble the corresponding part of the Crook Burn section 1¼ miles to the south and are mostly inclined steeply to the south-east.

The measures crop out in two separate reaches of the sike. In the lower reach, between the faults numbered 1 and 6 in Fig. 14, the section is as follows:

	ft
M.A.14	
Breccia, fine dark algal with algoolitic bands [5099 8027] ..	1¾
Sandstone, grey micaceous flaggy	4
Not exposed	8
M.A.13	
Limestone, dark grey fine-grained; algoolitic bands containing *Girvanella ducii* and *G. nicholsoni;* ostracods and bivalves at base	1½
Sandstone	4
Not exposed; shale debris; plant remains	1½
Limestone, dark fine-grained; *G. ducii*, bivalves and ostracods ..	1
Shale, grey sandy rubbly	1
Not exposed; shale debris	3
Sandstone, grey brown-weathering curly bedded flaggy ..	1½ ft to 2
Shale, grey; sandstone bands ..	2

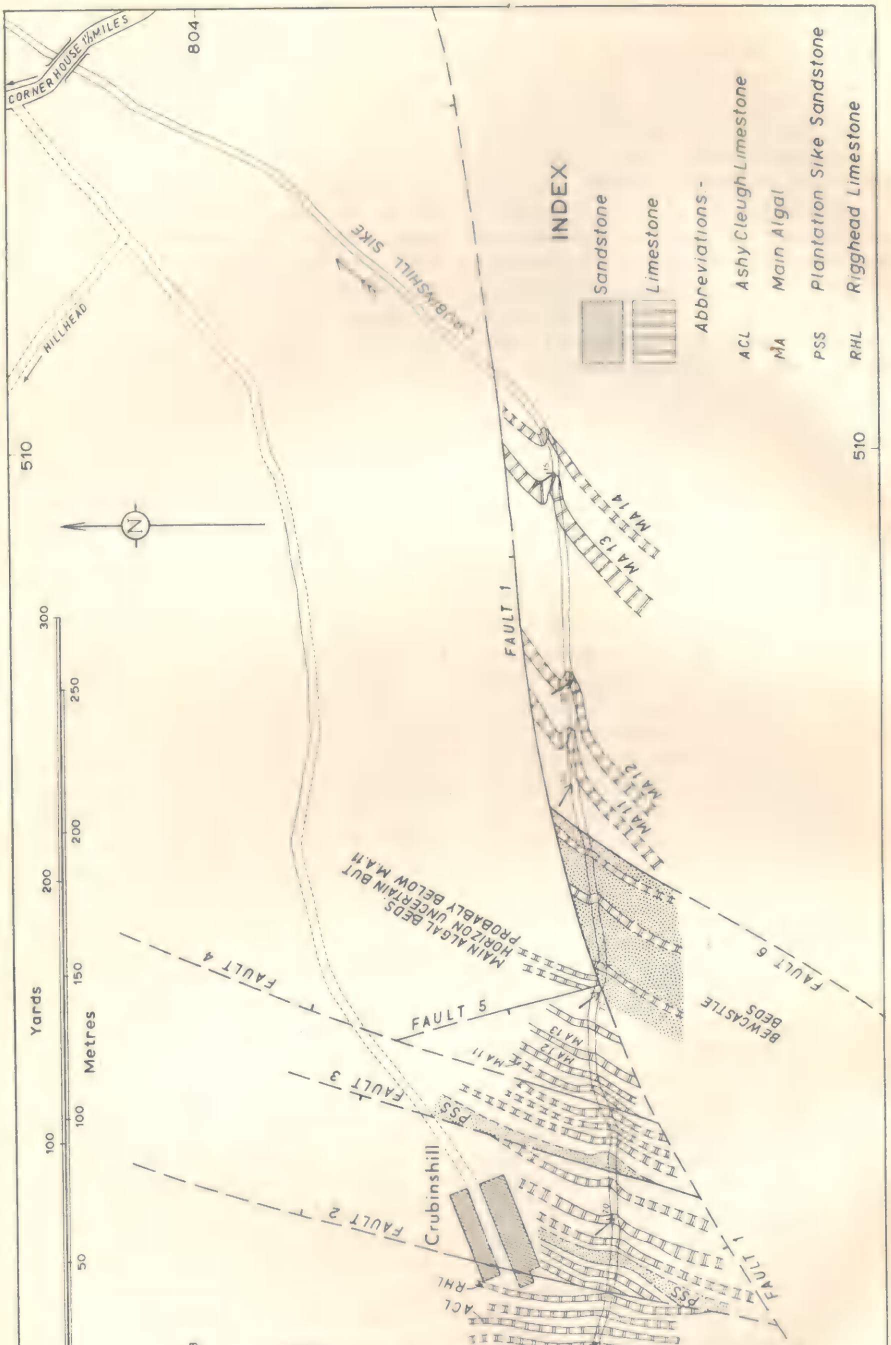


FIG. 14. *Outcrops of Bewcastle and Main Algal beds in Crubinshill Sike*

	ft
Shale and sandstone	11¼
M.A.12	
Limestone, dark fine-grained; algoolitic at top *Ortonella kershopensis*	1½
Limestone; shaly partings	¾
Shale, dark	1
Shale, calcareous; bivalves	3
Shale, sandy; bivalves at base	3¼
Sandstone	4
Not exposed	2
M.A.11	
Limestone, dark fine-grained algal; dolomitized at base; rare ooliths; *Bevocastria conglobata*?, *Girvanella amplifurcata*, *Ortonella kershopensis*, *O. tenuissima*, *Modiolus sp.*, *Spirorbis sp.* and ostracods	4
Not exposed	3
Limestone, dark grey fine-grained algoolitic; *Spirorbis sp.*, *G. incrustans* and *O. furcata*?	1½
Limestone, dark grey nodular	¼
Limestone, dark fine-grained algoolitic; *Spirorbis sp.*, *G. ducii* and *G. nicholsoni*	2
Shale, dark grey sandy; thin rubbly sandstone partings; ?*Myalina sp.* at top	6
Sandstone, grey flaggy micaceous	2
Fault No. 6	—

For about 60 yd upstream from the fault numbered 6 in Fig. 14 Bewcastle Beds are exposed (p. 33). They are cut off by the fault numbered 1, which brings down the following section:

	ft
Fault No. 1	—
Limestone, dark fine-grained algal and algoolitic; sandy bands and flaggy partings; *Ortonella furcata* [5079 8027]	2½
Shale, dark sandy micaceous	¾
Shale, dark	3
Cementstone, dark fine-grained	¾
Shale, dark sandy	2
Fault No. 5	—

The position of these beds within the sequence is uncertain, but they are believed to lie below M.A.11. Upstream from the fault numbered 5 in Fig. 14 the upper part of the Main Algal succession (No. 2 in Fig. 13) is repeated beneath 8 ft of sandstone and sandy micaceous shale as follows:

	ft
M.A.14	
Limestone, fine-grained dark nodular; oolitic towards base; algal at top; *Bevocastria conglobata*, *Girvanella ducii*, *Ortonella furcata*, *O. kershopensis*, *O. tenuissima*?	1
Sandstone, grey hard rooty	2
Sandstone, massive flaggy	10½
Not exposed	5½
Shale, dark	5
Shale, dark calcareous; fossiliferous	¼
M.A.13	
Limestone, fine-grained dark; algal pellets and nodules; slickensided and veined at base; *Bevocastria conglobata*, *Girvanella amplifurcata*, *G. magna*, *Ortonella furcata*, *O. kershopensis*	5⅓
Shale, dark grey sandy	1⅓
Sandstone, hard shaly; plant debris	⅓
Shale, dark sandy papery	1¾
Sandstone and shale; bivalves near base	9
Shale, calcareous; fossiliferous	¼
M.A.12	
Limestone, dark fine-grained; ooliths; *Girvanella ducii*, *G. wetheredii*, *Ortonella furcata* and shell debris	½
Shale, dark grey sandy; rare bivalves	2¼
Sandstone, grey hard rubbly micaceous	1½
Limestone; algal breccia	⅓
Not exposed	up to 1
Sandstone, flaggy	9
Shale, sandy	3½
Shale, calcareous; bivalves	3½
Shale, dark calcareous rubbly; abundant bivalves	⅓
Limestone, fine-grained crystalline; bivalves	½
Shale, dark calcareous; abundant bivalves	1
M.A.11	
Limestone, dark fine-grained nodular; oolitic at top; *Girvanella spp. nov.*	1¼
Limestone, crystalline; rare algal growths; ostracods abundant in bands	2
Not exposed	1

	ft
Limestone, dark fine-grained oolitic algal; crystalline at base; *Girvanella ducii*, *G. sp. nov.* A, *Stacheia sp.*, bivalves and ostracods	2
Fault No. 4	—

About ½ mile downstream, between the road-bridge and the Langley Burn, are further exposures presumed to be of Main Algal Beds. One exposure [5116 8044] lies to the west of two north-westerly faults which are about 25 yd apart. It consists of 1½ ft of dark grey shale overlying 1½ ft or more of dark grey oolitic algal limestone with bivalves. Between the two faults 17 ft of sandstone and sandy shale with plants overlie 3 ft of dark shales with bivalves, fish scales and ostracods. The shales have been brought down by the eastern fault against 3 in of shale with *Myalina sp.*, overlying at least 1 ft of grey crystalline limestone which is shelly at top and ostracodal below. These beds dip at a low angle to the west-north-west, but about 10 to 15 yd downstream, and possibly separated from the previous exposure by yet another fault (not shown on the maps), is a small syncline, the eastern limb of which [5122 8046] dips west at 30°. It is formed by a thin limestone containing both nodular and '*Collenia*' algal forms and ostracods overlying shaly sandstone.

Cuddy's Burn. The Cuddy's Fault trends parallel to, and locally follows, the burn northwards for about half a mile, from near St. Cuthbert's (or Cuddy's) Hall. Sections are numerous, but disconnected and disturbed. They include algal limestones with both nodular and '*Collenia*' forms, but they cannot be correlated with the numbered horizons, and some of them may belong to the Bewcastle Beds.

The sections given below are therefore described relative to the Cuddy's Fault and in the order in which they occur, commencing with the northernmost and working downstream towards St. Cuthbert's Hall:

[5211 8180], east of fault:

	ft
Sandstone, grey medium-grained current-bedded; shaly and flaggy at base	6
Not exposed	3
Shale, blue-grey sandy	1
Not exposed	6
Sandstone, grey flaggy micaceous	8
Shale, dark grey sandy; few ostracods and small bivalves	6
Shale, grey, weathering rotten and brown	1½
Shale, black carbonaceous . .	¼
Sandstone, brown-grey shaly flaggy	4
Sandstone, grey brown-weathering medium-grained current-bedded	11
Sandstone, brown-weathering calcareous; bivalves	½
Sandstone, grey shaly flaggy; massive bands	4
Shale, grey sandy; passing upwards into shaly flaggy sandstone . .	5
Shale, grey sandy; bands of hard nodules; plants	6
Sandstone, grey shaly flaggy; harder bands; plant debris . .	4
Not exposed	1
Limestone, grey crystalline; few bivalves	¾
Sandstone, grey shaly flaggy micaceous	1½
Not exposed	8
Limestone, dark grey shaly crystalline	¾
Not exposed	1
Shale, dark grey micaceous; plants	1
Not exposed	3½
Limestone; shaly bands; sparsely oolitic at base; rare ostracods at top	3
Sandstone, grey micaceous shaly flaggy; sandy shale bands . .	6

[5208 8178], west of fault, in right bank:

	ft
Limestone, grey algal; ooliths and '*Collenia*' structures; ?*Solenopora* (loc. 19a)	1
Shale, dark grey; calcareous bands	3

[5210 8177], east side of fault:

	ft
Sandstone, flaggy; shaly partings	—
Limestone, dark grey, and calcareous shale; ostracods and other fossils picked out in pyrite . .	1½
Sandstone, flaggy; shale partings	—
Not exposed	6
Sandstone	2
Shale, grey sandy, and shaly flaggy sandstone	5
Limestone, grey crystalline veined; ostracods	¾
Sandstone, grey shaly flaggy . .	3
Not exposed	3
Sandstone, shaly flaggy; vertical	4

	ft
Shale, calcareous nodular	¼
Shale, grey sandy	1

[5208 8169], immediately adjacent to east of fault:

Veined crystalline limestone forms crest of sharp anticline; 40 yd upstream a 3-in limestone at or near the same horizon contains *Serpula sp.* and *Spirorbis sp.*

[5209 8164], east of fault, left bank:

	ft
Limestone, grey crystalline; ostracods and bivalves; almost vertical; slickensided	2
Shale, grey; veined; almost vertical; slickensided	1

[5205 8158], west of Cuddy's Fault and adjacent to parallel, subsidiary faults between east and west banks:

(a) West bank: section on downthrow side of subsidiary fault

	ft
Shale, grey very sandy micaceous; a few mussels	2
Limestone, grey shaly; abundant mussels	½
Cementstone; ostracods	¼
Sandstone, grey shaly rubbly	1½
Shale, grey sandy	1
Sandstone, flaggy	1

(b) East bank: section on downthrow side of subsidiary fault

	ft
Shale, grey very sandy	2
Limestone, grey crystalline; ostracods and ?bivalves	up to ½
Not exposed	½
Limestone and cementstone; ostracods (correlative of 9-in limestone in west bank)	¾
Shale, grey sandy	2
Sandstone, grey flaggy	2½
Shale, grey	1

(c) East bank: section on upthrow side of subsidiary fault

	ft
Limestone, grey shaly; ostracods and bivalves	1
Shale, grey sandy	3
Limestone, grey shaly impure; ostracods	1
Shale, grey sandy; plants	1

[5202 8142], west of fault:

	ft
Limestone, dark grey fine-grained sparsely oolitic; *Girvanella ducii* and *Ortonella kershopensis* (loc. 19b)	1
Shale, sandy and flaggy sandstone	—

[5201 8140], west of fault:

	ft
Shale, grey hard; abundant ostracods in calcareous bands	3
Cementstone, grey; abundant ostracods at base	¼
Sandstone, grey rubbly	¾
Shale, grey; sandy at base; plants	4
Sandstone, grey micaceous rubbly	3

[5202 8136], west of fault:

	ft
Limestone, grey fine-grained crystalline	1+
Shale, dark grey calcareous nodular; abundant *Serpula sp.*	½
Shale, dark grey slickensided and veined; calcareous nodules; few ostracods at base	¾
Limestone and cementstone in thin bands; abundant ostracods and *Serpula sp.* at base	¼
Shale; slickensided	½
Sandstone, grey micaceous flaggy; shaly partings	¼
Shale, dark grey hard sandy	1

[5202 8133], west of fault:

	ft
Shale, hard grey white-weathering	1
Limestone, grey fine-grained crystalline; ostracods and *Ortonella kershopensis* (loc. 19c)	4

[5202 8131], west of fault:

	ft
Cementstone, grey flaggy	1
Mudstone, grey calcareous; brecciated	1¾
Shale, hard grey; slickensided	1

[5203 8128], east of fault:

	ft
Sandstone, grey-brown flaggy; with more massive bands	up to 12
Shale, grey-blue sandy; rubbly at top; locally cut out by overlying sandstone	3½
Sandstone band; locally cut out by overlying sandstone	½
Shale, grey-blue sandy	3
Shale, black rusty-weathering; ostracods	1
Limestone, grey nodular shaly; ostracods and bivalves including *Aviculopecten sp.*	¼
Shale, grey sandy; a few ostracods and bivalves	¼

	ft
Limestone, grey impure; alternating with bands of grey calcareous shale; ostracods, *Spirorbis sp.*, few bivalves	2½
Shale, grey sandy calcareous ..	2
Limestone, grey to grey-blue crystalline fine-grained; rubbly bands; ostracods, *Spirorbis sp.*, bivalves and microfossils	4

[5202 8199], east of fault, right bank:

Sandstone, brown medium-grained flaggy	2
Sandstone, grey micaceous flaggy; plant debris	3
Not exposed	1
Limestone, grey fine-grained; ooliths; *Spirorbis sp.*, ostracods, '*Collenia*' structures, *Aphralysia*?, *Bevocastria conglobata*, *Garwoodia gregaria*, *Ortonella furcata*, *O. kershopensis* (loc. 19f)	3
Sandstone, flaggy	—

[5199 8114], west of fault, at the ford where the bridle track crosses the stream:

Limestone, dark grey; ooliths, festoon structures, algal nodules; *Bevocastria*? and *Ortonella*? (loc. 19e)	2

[5198 8114], west of fault:

Shale, grey weathering white hard	1½
Shale, crushed and flaggy sandstone	—
Thrust over	
Limestone, grey fine-grained; ostracods, bivalves and *Serpula sp.*; rubbly reef-like infilling and algal festoon structures at base, with *Aphralysia sp.*, *Bevocastria conglobata*, *Garwoodia gregaria*, *Girvanella ducii*, *Gymnocodium sp.*, *Ortonella furcata*, *O. kershopensis* (loc. 16d)	about 6
Shale, grey hard calcareous ..	¾
Shale, dark grey rotten; abundant bivalves and other shell debris ..	½
Shale, grey sandy	2
Shale, grey calcareous; abundant bivalves	1½
Shale, grey; ostracods, bivalves including *Aviculopecten sp.* at base	1
Cementstone, dark grey	¼
Shale, grey; bivalves and ostracods	3
Limestone, dark grey impure; ostracods	2½
Shale, dark grey; ostracods; quartz veins at base	2

The algal band is probably the 'Main Reef' of Garwood (1931, p. 126) although not necessarily M.A.12

[5197 8114], west of fault:

	ft
Sandstone, greenish grey-brown rubbly shaly	2
Shale, grey micaceous sandy; rubbly at top; thin rotten calcareous band at base containing bivalves and brachiopods ..	4
Sandstone, green-grey rubbly flaggy; roots	6
Shale, grey sandy	¼
Sandstone, grey; shale partings; calcareous and nodular at base ..	2
Shale, grey sandy rubbly; a few bivalves at base	7½
Shale, dark grey sandy; rhynchonellids, ostracods, bivalves including *Aviculopecten sp.*.. ..	5
Shale, grey rubbly sandy; ostracods	4
Not exposed	3
Limestone, dark grey fine-grained; thin bands of cementstone; *Spirorbis sp.*, *Girvanella nicholsoni*, *Koninckopora*?, *Ortonella furcata*, *O. kershopensis*, orthocone nautiloids and ostracods at base (loc. 19g)	8
Limestone, dark grey fine-grained crystalline; bivalves and ostracods	¾
Shale, dark grey hard calcareous; ostracods	⅓
Limestone in thin nodular bands, fine-grained; shale partings; abundant ostracods	¼
Shale, dark grey; slickensided and veined	¼
Limestone, grey crystalline; finer-grained at base; ostracods, *Spirorbis sp.*	2
Shale, dark grey hard calcareous	about ½
Shale, grey very hard splintery; nodular; contorted against small fault	—

[5199 8107], east of fault:

Limestone, dark grey fine-grained; small ?crustacea and bivalves ..	2
Shale, calcareous; ironstone and	

	ft
limestone bands; shells and microfossils	1½
Limestone, black to dark grey, weathering pale grey; abundant microfossils; abuts against cross-fault	1

[5199 8106], east of fault:

	ft
Shale, black calcareous; many small fossils including *Spirorbis* and pectinids	1 in
Shale, greyish green; plant-like markings.	¼
?M.A.12	
Shale, dark grey; algal nodules, pectinids and other bivalves	¼
Limestone, dark grey fine-grained; *Garwoodia gregaria*, *Girvanella amplifurcata*, *Ortonella furcata*, *O. kershopensis* (loc. 19h)	1 to 2

[5198 8104], east of fault; overlies previous section:

	ft
Sandstone, grey medium-grained, rooty at top [5200 8098]	6 to 8
Not exposed	3½
Shale, grey sandy; thin sandstone partings	2¼
Sandstone, fine flaggy	¼
Rottenstone, brown	¾
Shale, grey; bands of rottenstone	¾
Shale, dark grey; *Myalina sp.*	½
Shell-bed; abundant *Myalina sp.*	⅓
Shale, hard grey smooth; ironstone nodules; rare shells	1½
Shale, grey thinly bedded	1
Sandstone, grey-brown flaggy; shells at top	1⅓
Fireclay, dark grey to greenish grey; ganister at base	2
Shale, grey sandy micaceous rooty	3
Sandstone, flaggy	3 to 4
Shale, grey sandy; finer-grained at base; *Myalina sp.*	2
M.A.13	
Limestone, grey shaly and calcareous shale; *Myalina sp.*	½
Limestone, black cherty; shell debris, gastropods, bivalves and algal nodules at base	1⅓
Limestone, dark; abundant bivalves	¾
Limestone, dark grey shaly; sandy bands at base; *Serpula sp.*; and rare *Myalina sp.*	1¼
Limestone, dark grey fine-grained	⅓
Shale, grey sandy	½
Not exposed	3 to 4
Limestone, black fine-grained cherty; obscure fossils	⅓
Sandstone, brown hard flaggy	1
Sandstone, grey very micaceous rooty flaggy	1½
Small fault	
Sandstone, brown medium-grained rooty	1
Shale, sandy	¾
Sandstone, shaly flaggy	3
Shale, grey sandy; rare plant debris and ?crustacea [5198 8104]	2

[5204 8088], east of fault, and south of easterly branch-fault; between the latter and mouth of Rispie Cleugh:

	ft
Shale, weathering rusty	1
M.A.11	
Limestone, rubbly nodular algal; rare shell debris	1½
Not exposed	8
Sandstone	about 19
Not exposed	4
Limestone, black fine-grained; vertical	1¼
Not exposed	3
ORBICULOIDEA SHALE	
Shale, dark grey to black; bivalves and *Orbiculoidea sp.*	2½
Shale, dark grey hard; bands containing abundant bivalves including *Sanguinolites sp.*	3½
Shale, grey nodular	1⅓
Limestone, black cherty; *Serpula sp.*	¾
Shale, grey calcareous; *Serpula sp.* at base	1¾
M.A.10	
Limestone, grey veined cherty	1¼
Limestone, grey fine-grained earthy crinoidal; shell debris	6¾
Limestone grey fine-grained cherty; black partings; ?fossiliferous near base	5¼
Not exposed	⅓
Limestone, dark grey very hard impure; ostracods	½
Shale, dark grey hard calcareous; abundant bivalves	¼
Limestone, grey hard; rare brachio-	

	ft
pods and abundant bivalves	1
Cementstone, grey	¼
Limestone, purplish grey thinly bedded lenticular; shale pellets; rare *Spirorbis sp.* and ?ostracods up to	¾
Shale, grey	¼
Not exposed	1¼
Limestone, grey shelly; abundant bivalves	½

Between the mouth of Smithy Gill and the locality downstream where the Cuddy's Fault, represented by at least three fractures, crosses the stream, are the following short sections, mostly folded and disturbed:

	ft
[5201 8059], right bank:	
Limestone, grey fine-grained; ostracods	1
Shale, dark grey calcareous; ostracods	1
Limestone, grey fine-grained; ostracods at base and algal nodules with radial structure at top	2
Not exposed	5½
Limestone, grey fine-grained; shaly at base; crystalline and ?crinoidal at top; ostracods and bivalves	2½
[5198 8059], left bank:	
Shale, grey sandy micaceous	2
Shale, dark grey; calcareous nodules; ostracods and bivalves	2
Limestone, grey dolomitic fine-grained; crinoids and brachiopods	¾
Limestone, grey sandy and crinoidal in topmost 1 in; grey, fine-grained with algal nodules; *Serpula sp.* in bottom 1 in at one locality	2
Cementstone, brown dolomitic flaggy	½
Shale, grey sandy micaceous	3
[5196 8060], beds folded into syncline:	
Shale, dark grey	3
Limestone, dark grey fine-grained; reticulate veining; weathers into nodules	¾
Limestone, dark grey shaly; thin bands of cementstone; bivalves and ostracods	2½
Shale, calcareous	⅓
Limestone, dark grey fine-grained; bands of cementstone; algal nodules at top; thin shaly partings at base; basal layers veined and ostracodal	4¾
[5194 8060], adjacent to easternmost fault and folded into gentle syncline:	
Limestone, grey fine-grained; gastropods and bivalves	¾
Shale, dark grey	¾
Shale, grey very sandy micaceous	2
Shale, dark grey; 1-in band of grey cementstone; contorted and ?faulted at base	4½
Cementstone, brown-grey; weathered cavities	¼
Shale, dark grey calcareous; a few small bivalves and ostracods	2
[5192 8060], monocline between two faults:	
Shale, dark grey, associated with	—
Limestone, grey fine-grained; rare *Serpula sp.*; bands of dark cementstone and thin shaly partings	6
[5191 8060], beyond fault forming western limit of previous exposure:	
Shale, grey sandy micaceous	1½
Limestone, grey fine-grained	¼
Shale, dark grey; contorted band; becoming very sandy at base	6
[5189 8059], west of fault-belt (may be Bewcastle Beds):	
Shale, calcareous shale and cementstone in alternating bands	2
Sandstone, grey brown-weathering flaggy; calcareous at base	1½
Shale, grey; calcareous bands containing *Serpula sp.*	¾
Limestone, grey fine-grained crinoidal highly veined; vertical slickensides	¾
Shale, grey	1½

At a sharp bend [5196 8057] about 50 yd downstream from the previous exposure, are 2 ft of algoolite overlain, after a gap of several feet, by 2 ft of cementstone with *Spirorbis sp.* The dip is about 35° to the south-east and the beds are on the strike of Bewcastle Beds exposed south-east of Graham's Onset in the Bailey Water and the Langley Burn (p. 32); it is thus possible that these measures belong to the Bewcastle Beds.

Hollin Cleugh. Algal, serpulid and ostracodal limestones and associated strata presumed to belong to the Main Algal Beds are exposed sporadically in Hollin Cleugh, above and below the road-bridge, and in a small tributary to the parent stream at the latter locality. The following sections are listed in order downstream.

[5275 8048]:

	ft
Shale, dark grey; plants	—
Limestone, dark grey; full of algal nodules; *Aphralysia*?, *Bevocastria conglobata*, *Garwoodia gregaria*, *Ortonella furcata*, *Gymnocodium*? (loc. 20a)	2
Limestone, dark grey oolitic; ostracods and bivalves	3

[5269 8045]:

Limestone, grey fine-grained; ostracods, *Spirorbis sp.*, bands of small algal nodules with *Solenopora garwoodi* (loc. 20b)	2
Shale, dark grey	¼
Shale, grey rubbly; sporadic plants	¼

[5266 8044]:

Sandstone, micaceous flaggy; shaly bands; shale at base	6

[5263 8032], left bank:

Limestone, grey fine-grained crystalline	¼
Shale, grey rubbly	¾
Limestone, grey fine-grained crystalline; rare ostracods ..	1

[5261 8037], right bank; the relationship to previous section is obscure

Limestone?, grey shaly crinoidal ..	—
Shale, grey	—
Sandstone, grey shaly flaggy	about ½
Shale, grey sandy	1
Shale, grey	1
Shale, grey hard calcareous	about 1
Limestone, brown-weathering fine-grained crystalline flaggy; abundant *Serpula sp.*	1¼
Shale, grey; sandy at top ..	1
Cementstone, grey; reticulate weathering on upper surface ..	¼
Shale, grey sandy; sandstone bands	½

[5220 8010], 100 yd W. of road-bridge; a few yards below junction with tributary:

	ft
Sandstone	1
Limestone, grey sandy oolitic ..	1½
Cementstone, brown-weathering soft	2
Sandstone, brown medium-grained	1
Not exposed	1
Shale, brown-weathering rotten ..	1
Sandstone, brown-weathering shaly flaggy; plant debris	3
?Fault	
Shale, dark grey blocky	1
Shale, grey hard calcareous ..	1
Shale, grey soft	5½
Shale, hard grey sandy calcareous; ostracods	½
Shale, grey	1

[5227 8010], in tributary about 5 yd W. of culvert under road:

Shale, grey calcareous; bivalves, ostracods and small turreted gastropods	½
Cementstone, grey	⅓
Shale, grey	1

River Black Lyne (loc. 21). The topmost measures of the Main Algal Beds are exposed as follows in the River Black Lyne, between 100 and 200 yd upstream from the junction with Lancy's Cleugh:

	ft
CAMBECK BEDS	
Calcareous shales and limestones (p. 70)	30 to 35
MAIN ALGAL BEDS	
M.A.14	
Limestone, shaly; rare algal nodules [5566 8460]	¾
Limestone, blue	2½
Not exposed	?
Shale; shell debris and ostracods	½
Not exposed	3½
M.A.13	
Limestone; algal nodules and alga-encrusted orthocones ..	½
Not exposed	2 to 3
M.A.12	
Limestone, shaly bands; abundant algal nodules and orthocone fragments	4
Not exposed	?
Limestone, grey; ostracods and ?algal pellets [5573 8464]	1¾
Not exposed	4
Shale, calcareous; a thin limestone band containing abundant ostracods	4

Farther down the river, between the mouth of Robbie's Grain and the Bellevue Fault, are several disconnected exposures including 2 ft of algoolite overlain by fine-grained calcareous sandstone [5525 8223] and 1 ft of ostracod oolite [5512 8276].

Between the Bellevue Fault and a branch-fault which crosses the river near Black Lyne House are several more exposures of Main Algal Beds. The northernmost [5422 8042] is as follows:

	ft
Limestone, blue-grey hard; worm-like markings	2
Limestone, dark grey shaly; ostracods and shell debris	1½
Limestone, grey-blue; crinoid ossicles	½
Limestone, dark grey; ooliths; nodules of *Garwoodia gregaria* and *Girvanella ducii*	¾
Not exposed	
Sandstone, cream-grey medium-grained current-bedded	3

Farther downstream, beneath a sandstone, is a 2-ft limestone with rare *Serpula sp.* [5428 8030] and a 4½-ft brown-weathering dolomitic limestone with ostracods at the base [5427 8027]. A longer section is seen at the mouth of Parkside Sike [5428 8024] as follows:

	ft
Sandstone and shale, brown-weathering calcareous; ostracods and plant debris	2
Limestone, rubbly; a few ostracods	½
Shale, grey; small algal nodules	¼
Limestone, grey rubbly	2
Not exposed	3
Sandstone, cream-brown fine-grained current-bedded	4 to 5
Limestone, blue-grey algoolitic	3¾
Not exposed	1½
Limestone, blue-grey algoolitic	1
Cementstone, fawn-grey; crinoid ossicles	3

Further exposures downstream include 6 ft of creamy brown fine-grained current-bedded sandstone overlying grey shales with a 7-in band of dolomite [5421 8012], and 2 ft of grey limestone with ostracods and microfossils. The position of the Bellevue Fault is marked on the left bank [5428 7999] by contorted grey sandy shales with bands of sandstone. South of the fault, the following left bank exposure [5426 7994] is the only known representative of the Main Algal Beds:

	ft
Limestone, grey shaly	¼
Limestone, dark grey; abundant small algal (?*Garwoodia*) nodules	¼
Cementstone, grey; ostracods	2¾

Robbie's Grain. The base of the Main Algal Beds is exposed [5596 8402] in the right bank, 40 yd upstream from the junction with Shortshank Sike, where the section of M.A.1 is:

	ft
Limestone, blue-grey; microfossils and small algal pellets	¾
Limestone, flaggy; microfossils	1
Not exposed	1½
Limestone, brown-weathering very sandy; bands of calcareous sandstone	4

The same limestone is also exposed [5582 8380] downstream along the strike as follows:

	ft
Limestone, nodular algal	¾
Limestone, grey-blue; ostracods	1½
Not exposed	3
Limestone, blue-grey sandy impure	3
Limestone, shaly	1½
Limestone, sparsely oolitic towards base; abundant *Serpula sp.*	4½
Algoolite; *Serpula sp.* and ostracods	2

Another exposure of part of this limestone still farther downstream [5574 8373] comprises:

	ft
Shale	—
Limestone, with shaly bands	1¼
Limestone; algal nodules abundant at base	2
Shale, with calcareous bands; rare algal nodules	½
Limestone, blue-grey blotchy	1¾
Shale	—

The Hole of Lyne Fault passes close to the east of this exposure. Towards the mouth of Robbie's Grain are higher beds of uncertain correlation. About 30 yd downstream from the mouth of Dry Sike, 1 ft of impure crinoidal limestone, with brachiopod spines, rests on 1 ft of shale; and 60 yd upstream from the confluence with the River Black Lyne are the following:

	ft
Algoolite, hard; rare '*Collenia*'-type growth-forms	1
Not exposed (probably algoolite)	2
Sandstone, fine-grained current-bedded rooty	4

Another band of algoolite, 1 ft or more thick and at a slightly lower horizon, is exposed [5540 8342] about 20 yd up from the mouth of the stream.

Farther up Robbie's Grain, between 500 and 1100 yd from the mouth of Shortshank Sike, is an outcrop of Main Algal Beds bounded by faults. The southernmost, the Hole of Lyne Fault, follows the stream for a considerable distance and, in consequence, both the amount and direction of the dip are very variable throughout the outcrop; indeed the beds may be inverted in some places. As at Cuddy's Burn correlation is difficult because no long continuous sequence can be made out. The following sections are therefore listed in downstream order and are not necessarily in correct stratigraphic sequence: all lie to the north of the Hole of Lyne Fault.

[5667 8455]:

	ft
Limestone; abundant small algal nodules	2½
Limestone, blue-grey; with rare ooliths	4
?Unexposed interval	
Algoolite, dense; '*Collenia*'-type growth-forms at top and algal nodules in basal 6 in	1½
Limestone, grey	½
Shale, grey sandy	—

The algal limestone at the top of this sequence is repeated downstream [5665 8452]. It is followed, at 5-yd intervals, first by 2 ft of blue-grey limestone with microfossils and then by 2¾ ft of algal limestone with rare *Serpula sp.* and with good '*Collenia*'-type growth-forms in the basal 2 ft which is densely algoolitic. A cross-fault separates this exposure from the following sequence [5661 8449]:

	ft
Limestone, grey; ostracods and small ?algal pellets	¾
Shale	1
Shale, grey calcareous	¼
Sandstone	⅔
Shale, grey-blue	5
Not exposed	6
Limestone; abundant small algal nodules (equivalent to the upper algal limestone at 5667 8455)	1½
Limestone, shaly	about 2½
Limestone, oolitic; small algal pellets	2
Limestone, brown-grey fine-grained; ostracods	4
Shale, calcareous; thin limestone bands	3

[5665 8445]:

	ft
Sandstone, fine- to medium-grained current-bedded; prominent curled bedding	6
Not exposed	8
?BIRKY CLEUGH LIMESTONE	
Limestone, grey; few oolites	2
Cementstone	—
Poorly exposed interval, including a 2-ft yellow-weathering limestone, with algal pellets and *Serpula sp.*	4
Limestone, oolitic and algal	5
Not exposed	about 8
Sandstone, fine-grained massive; *Stigmaria sp.*	2
Not exposed	24
Limestone, blue-grey oolitic; small algal nodules [5653 8443]	7
Limestone, grey	1
Not exposed	8
Limestone, weathering brown	1
Sandstone, shaly flaggy	1¾
Sandstone	4½
Shale	—

[5649 8441]:

	ft
Limestone; small algal nodules	2¼
Limestone, brown-weathering	1

[5646 8440]:

	ft
Limestone, decalcified at top	4
Sandstone, fine-grained, brown-weathering	3½

[5643 8437], dip north-west at 70°, probably inverted:

	ft
Sandstone, flaggy	24
Shale, grey	3
Sandstone, shaly flaggy	1
Sandstone, fine-grained flaggy	3
Limestone, grey brown-weathering	3
Limestone, blue-grey; ooliths	1½ to 2

	ft
Limestone, grey; algal nodules at base	2¾

[5637 8433]:

Limestone, brown-weathering sandy flaggy	1¼
Sandstone, grey fine-grained; Serpulid tubes at base	1
Shale, dark grey	—

[5634 8434]:

Limestone, blue; small algal nodules, ooliths and ostracods	3
Shale, dark grey	½
Limestone, grey brown-weathering; shaly at base	1¼
Shale	—

This section was measured on a slipped block adjacent to the fence. The upper limestone is again exposed downstream [5634 8431] where it is 2 ft thick and is folded down towards the south-west.

At the western margin of the outcrop [5631 8428] 2 ft of nodular algal limestone are juxtaposed, on the eastern side of the limiting fault, against shale overlying algal limestone.

The Beck. Further disconnected sections of Main Algal and Cambeck beds are exposed in The Beck between the Hole of Lyne and Beckhead–Binky Linn faults. They include several algal limestones with typical '*Collenia*'-type growth-forms and nodule beds. Few of them can be correlated with the type sequence and the sections are given below in order of occurrence downstream.

[5701 8290]:

	ft
Sandstone	—
?M.A. 12 or 13	
Shale, calcareous; full of small algal nodules	1½
Limestone; rare small algal nodules	1
Shale, calcareous; abundant algal nodules in small and large aggregates	½

A few yards downstream is a thin limestone dipping aberrantly north by west at 50°.

[5689 8286] and downstream for about 100 yd:

	ft
Sandstone, fine-grained flaggy micaceous; small ripple marks	3
Not exposed	6
Limestone, grey weathered yellow; ostracods and microfossils; brown cementstone with ostracods at base. This is probably equivalent to the limestone exposed [5751 8047] in Little Hare Grain (p. 65)	2½
Not exposed	3
Cementstone; a few bivalves and ostracods	1
Not exposed	2
Limestone; abundant '*Collenia*'-type growth-forms uniting at top to form small domes	1¼
Limestone; many small algal nodules	⅓
Not exposed (probably sandstone)	2
Sandstone, fine-grained graded; finely current-bedded at base; some curled bedding	7 to 8
Not exposed	5 to 6
Limestone, grey; ostracods	4
Limestone, grey; worm-like markings	2½
Algoolite	2
Limestone, oolitic; many ostracods, ?*Garwoodia* and small algal nodules	¾

Beneath this section is a considerable thickness of sandstone which crops out intermittently for nearly 400 yd downstream and which is underlain by the following [5658 8269]:

	ft
Sandstone, fine-grained, shaly flaggy bands	6
Not exposed—some shale debris	about 9
Limestone, weathered yellow mostly cementstone; ostracods and rare bivalves; band of algoolite 2 ft above base	4½
Not exposed	6
Algoolite, decalcified and shattered in bands	3½
Shale, blue; shattered	2

Farther downstream [5612 8260] 4 ft of yellow-weathering algal limestone, with nodules and ooliths at top and with ostracods below, are folded into an anticline trending east-south-east.

[5551 8228], southern downthrow side of fault:

	ft
Sandstone, fine-grained flaggy	25
Shale, grey sandy	2
Limestone; a band of large nodules (loc. 22)	4½

	ft
Shale, grey; *Sanguinolites* and ostracods	2
Limestone; *Antiquatonia teres*, 1 in	—
Not exposed	10
Limestone; algae, '*Camarotoechia*' *sp.* and *A. teres*	1⅔
Not exposed	3
Limestone; algae and ostracods ..	1
[5539 8230]:	
Sandstone, shale bands	8
Limestone, impure earthy ..	½
Sandstone, shale bands	4

WHITE LYNE CATCHMENT

River White Lyne, west of Lyneholmeford (loc. 23). The uppermost 130 ft of the Main Algal Beds form part of a long continuous measured section (Appendix I, p. 314 and Fig. 13) which extends upstream in the White Lyne from its confluence with the River Black Lyne. The section is terminated at the base by a branching strike-slip fault across which it has not been found possible to make a detailed correlation. The lowest bed, exposed in the right bank [5121 7295], is M.A.8; it consists of nearly 3½ ft of pinkish serpulid limestone and is overlain by 3 ft of red marls and 15 ft of red non-algal limestone. There follows a gap in the sequence up to the upper part of M.A.9 which is doubtfully recognized a little farther downstream. M.A.10 consists of 14 ft of pink limestone [5120 7297] with sparse algal nodules and rare shell debris; it is overlain in the right bank by several feet of red shales which contain the '*Orbiculoidea* Shale' fauna (Appendix I). Nearly 20 ft higher in the succession is M.A.11, which comprises 4 ft of algal limestone with abundant nodules 3 or 4 cm in diameter (Pl.II) and with at least seven species of algae. It is separated by a thin sandstone from M.A.12 [5119 7299] which consists of 7 ft of pinkish limestone, including a 2-ft nodular algal bed near the top. '*Collenia*'-type forms in position of growth (Pl. II) indicate that the steep easterly dip of these beds is inverse. M.A.13 consists of 5 ft 4 in of sparsely nodular algal limestone and M.A. 14 appears to be non-algal at this locality.

Upstream towards the Kaysbank Fault are several short, faulted sections which, on structural grounds, might be expected to represent parts of the same sequence though they seem from their lithology to be lower beds. They include a 9-ft red limestone with 2 ft of massive algoolite at the base and with a band of algal nodules 3 ft below the top; it is exposed [5116 7289] in the left bank between two strike-slip faults. A further 9 ft of red limestone overlying 2 ft of algoolite are exposed [5114 7282] at the outside of the bend where the Kaysbank Fault crosses the river.

Strata cropping out between the Kaysbank Fault and one of the constituent fractures [5150 7260] of the Lyneholmeford Fault-belt are assigned to the Bewcastle Beds (p. 36), but those exposed between the last locality and the weir at Damhead are almost certainly of Main Algal age. For a stretch of about 100 yd the strata are vertical and include reddened sandstones and algal or algoolitic limestones up to 8 ft thick. Beyond the easternmost fracture of the fault-belt, however, the dips are more moderate and at least six small step-faults, all throwing down to the east with displacements of up to 10 ft, repeat the same beds along a 300-yd stretch of river extending east of Crook Bridge. This repeated sequence consists of 2 to 3 ft of pinkish compound nodular algal limestone overlying in turn a distinctively deep brick-red sandstone and a pinkish marl. The limestone is best seen in the river bed a few yards west of Crook Bridge. Garwood (1931, p. 124) considered that it represented the "Lowest algal pellet bed of Birky Cleugh and Green's Burn", but the compound nature of the algal growth is suggestive of a much higher horizon. Similar masses, for instance, occur in M.A.12 in Kirk Burn south of Stapleton church (p. 47).

Another limestone containing compound nodular algal masses is exposed in the left bank [5186 7241], north-east of Damhead, and a few yards upstream from the old weir there is an exposure in the left bank [5189 7236] of about 1½ ft of algoolitic microfossiliferous limestone. Still farther upstream, as far as the Mewsgate Fault, however, there is a thick cover of boulder clay through which only outcrops of sandstone [5195 7231] and marl [5204 7248] can be seen.

Show Burn. West of the Mewsgate Fault, the following strata, dipping steeply eastwards may belong to the Main Algal Beds:

	ft
Limestone, red and grey fine-grained folded	14
Not exposed	about 50
Sandstone, grey	3
Marls, variegated red and green ..	5
Limestone, red; veined by calcite	7

East of the Mewsgate Fault most of the exposures in Show Burn belong to the Cambeck Beds or to Middle Border Group, but the Main Algal Beds crop out at one locality [5442 7229] immediately west of the Bogside Fault. They are there represented by a thin grey, flaggy, nodular algal limestone containing abundant small pellets of ?*Garwoodia* in which the internal radial and concentric structure of the plant can be seen clearly with the aid of a hand-lens. East of the Bogside Fault, solid features obliquely cross the southern side of the valley and 2½ ft of nodular and ostracodal grey limestone are exposed in a shallow digging [5505 7225] opposite Lynes Moss Wood. Near the head of the valley, on the north side of a glacial overflow channel [5555 7221], 150 yd S.W. of Wintershields, is an old shallow quarry in which 6 to 7 ft of shaly nodular algal limestone still can be seen.

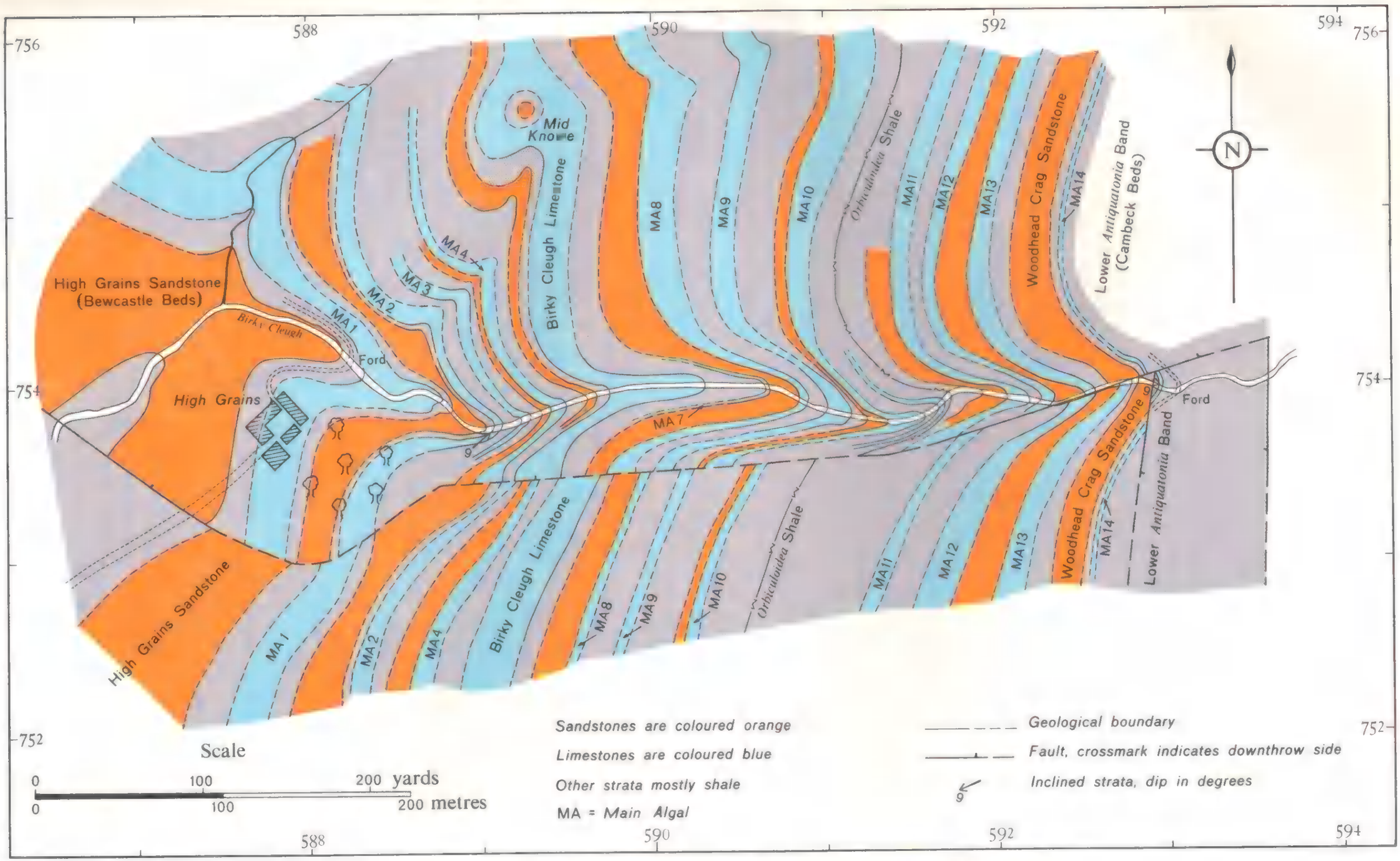
Whitberry Burn (loc. 24). A long continous section through steeply dipping beds of the Lower and Middle Border groups has been measured in Whitberry Burn. It extends down to include the upper half of the Main Algal Beds, with the Birky Cleugh Limestone [5229 7398] at the base. Full details are given in Appendix I, p. 319.

Birky Cleugh. The sequence in Birky Cleugh, east of High Grains Farm, is so well exposed that Garwood (1931, pp. 109–12) adopted it as the type section of the Main Algal Series. His 'condensed' sequence is more generalized, particularly in the lower part, than the section measured during the resurvey, (detailed in Appendix I and shown graphically in Figs. 13 and 15) but it is evident from comparison of the two sections that Garwood's 'worm' bed and 'Main Reef' are the equivalents of M.A.1 and M.A.12 respectively.

The basal member, M.A.1, is best seen in the right bank [5885 7540] a few yards above the High Grains ford where it consists of two elements. The lower comprises up to 1¾ ft of reef-like serpulid limestone with an uneven top; it is overlain by 12 ft of algoolitic and nodular algal limestone, with subordinate bands of unfossiliferous cementstone. About 26 ft of sandstone and sandy shale separate M.A.1 and M.A.2. The latter is exposed [5891 7538] in both banks and has a shattered appearance although there is no appreciable local faulting. M.A.3 is another serpulid limestone; it occurs a few feet higher in the sequence and is in turn succeeded by M.A.4, represented by 2 to 3 ft of massive oolite with algal patches [5894 7539]. The Birky Cleugh Limestone is the thickest limestone in the sequence and forms a prominent waterfall [5900 7540]; it consists of a lower 7½ ft of limestone and cementstone, with bands of algal nodules and algoolite (M.A.5), a median 10½ ft of sparsely shelly marine limestone with *A. teres*, and an upper 4 ft of nodular algal limestone (M.A.6).

The next algal band in upward sequence, M.A.7, occurs near the base of a thick sandstone and has a distinctive lithology. It is about 1 ft thick and consists of algal nodules in a matrix of yellow weathering calcareous sandstone. Above the sandstone lies M.A.8, comprising about 8 ft of algal-banded cementstone, with thin beds of algal shale near the base and 11 in of conspicuous algoolite 6 ft below the top. The algoolite contains ooliths ranging from 1.0 to 10.0 mm in diameter and exhibits graded bedding: it is best seen close to the waterline in the right bank [5910 7539] and is probably the 3-in oolite described by Garwood (op. cit., pp. 109–12). M.A.9 is separated from M.A.8 by 16 ft of sandy and calcareous shale. It consists of 9¾ ft of sparsely algal, cementstone, massive at top and base and forming a waterfall. M.A.10 consists of two layers of algal limestone with a median 2½ ft of nodular algal shale. The *Orbiculoidea* Shale crops out a few feet higher in the sequence in a small cliff on the left bank [5918 7358]. It contains a varied fauna, principally of bivalves such as *Sanguinolites sp.* and *Edmondia sp.* but with abundant *O. nitida* in a single layer about 4 ft above the base. The band is succeeded by almost 20 ft of sandstone and shale above which is M.A.11, represented by 2 ft of cherty nodular algoolite. The ooliths in this band grade through pisoliths to '*Osagia*'-type nodules. Together with the succeeding 2 ft of nodular shale the limestone occupies the bed of the cleugh for some distance upstream.

The nodular shale gives way in upward succession to 5 ft of sandy shale, overlain by



1500/68

FIG.15. *Sketch-map showing outcrops of Main Algal Beds in Birky Cleugh*

M.A.12 (Garwood's 'Main Reef') which crops out in the right bank [5924 7538]. It consists of 4 ft of shaly cementstone enclosing large compound nodular algal masses, as well as simpler '*Osagia*'-type nodules; the larger growths commonly encrust shells of orthocone nautiloids. Upstream from this locality a fault, downthrowing 10 to 12 ft to the north, obliquely follows the cleugh for about 60 yd and repeats in the left bank M.A.11, M.A.12 [5927 7538] and intervening beds. M.A.13, cropping out in the right bank is separated from M.A.12 by about 15 ft of sandy shale and sandstone. It is an 8-ft limestone of which the lower 5 ft are algal, while the upper 3 ft are shaly. The lower portion contains large compound, mamillated algal growths very similar to those of M.A.12, but displaying adherent *Spirorbis* tubules; the shaly bed contains abundant '*Osagia*'-type nodules 5 to 10 mm across in a layer about 1 ft below the top.

The overlying Woodhead Crag Sandstone is recognized in most of the nearby streams and forms a feature which can be traced easily along the fells. In Birky Cleugh it is only about 10 ft thick, but may be partly cut out by a small north–south fault [5932 7538]. On the western, downthrow, side is a shelly limestone with a band containing sparse algae at the base. The top of the Main Algal Beds is taken at the top of this band (M.A.14) which can be seen against the fault at the base of a small waterfall [5932 7538].

Bull Cleugh. In Bull Cleugh the measures between the High Grains Sandstone and the top of the Birky Cleugh Limestone, and between the base of M.A.12 and the top of M.A.14 are exposed completely (Fig. 13). Their lithology differs little from their equivalents in Birky Cleugh, but there is slight variation in the thickness of individual beds, particularly sandstones, although the total thicknesses are about the same. The *Serpula*-reef at the base of M.A.1 in Birky Cleugh is represented by 1 ft of algoolite in Bull Cleugh [5872 7575]. Similarly the serpulid M.A.3 limestone in Birky Cleugh here consists of 2 ft of sparsely oolitic cementstone underlain by shale with small '*Osagia*'-type algal nodules [5879 7582].

The Birky Cleugh Limestone forms a gently flexured outcrop which follows the stream for more than 150 yd, with the underlying sandstone exposed in the core of one of the flexures [5879 7600]. The basal 4 ft of grey cementstone are overlain first by 3 ft of nodular algal limestone, including 1 ft of algoolite, then by 9½ ft of limestone and shaly cementstone with *Antiquatonia teres*, and finally by 8 to 9 in of microfossiliferous algoolitic limestone with a few small '*Osagia*'-type nodules. The topmost few feet of the limestone are not exposed. Algal nodules in the stream bed [5879 7606] have a well-preserved internal structure: they closely resemble nodules exposed in the Show Burn (p. 60).

The succeeding 110 ft of the sequence, including M.A.7 to M.A.11 and also, contrary to Garwood's (op. cit., p. 112) observations, the *Orbiculoidea* Shale, are masked by drift. The next exposure in upward sequence is M.A.12 [5908 7620] west-south-west of Green Brae: like the overlying M.A.13 [5912 7626] it is a nodular limestone similar in lithology to their equivalents in Birky Cleugh, with characteristic compound algal masses which commonly encrust orthocone nautiloids such as *Orthoceras breyni*.

Between M.A.13 and M.A.14 are 30 to 35 ft of strata including 13 ft of Woodhead Crag Sandstone, and also including more sandy shales above M.A.13 than are seen in Birky Cleugh. M.A.14, at the top of the Main Algal Beds, is relatively inconspicuous, consisting of 2 to 3 in of sparsely algal shale [5920 7633].

Stack Cleugh. The base of the High Grains Sandstone crops out [5880 7469] at the confluence of the northern and southern branches of Stack Cleugh. In the northern branch a continuous sequence (details in Appendix I, p. 315 and Fig. 13) is exposed from the base of M.A.1 up to a sandstone overlying M.A.8: in the southern branch exposures are less continuous, but extend to about the level of M.A.12, south-west of Gilbert's Hill.

In the northern stream M.A.1 [5896 7478] consists of 2 ft of oolitic algal limestone overlying 5½ ft of cementstone; there is no *Serpula*-reef as in the southern stream [5888 7464] where it is 3 to 4 ft thick with an irregular upper surface and where the overlying algal limestone is 10 ft thick.

The strata between M.A.1 and M.A.2 in the northern stream include an algal band [5902 7477], which is additional to the type sequence in Birky Cleugh; it consists of 5½ in of algoolite overlying 5 in of algal limestone in which the growths envelop bivalve shells. M.A.2 [5905 7477] comprises 3½ ft of algal and oolitic limestone overlying 3 ft of massive algoolite. M.A.3 is cut out by a thick sandstone, which occupies the interval between M.A.2 and the incompletely exposed M.A.4 [5913 7478]. The Birky Cleugh Limestone [5920 7478] is 24 ft thick in the northern tributary, where it includes thin sandstone bands, but is not as well exposed as in the southern tributary [5909 7460], where it is 20 ft thick. In the northern stream a small sinuous north-westerly fracture [5927 7479] repeats the topmost 2½ ft of the limestone, which includes a 3-in band of alga-encrusted shells. A few yards farther upstream, on the northern, downthrow side of the same fault, 6 ft of shaly nodular algal limestone (M.A.8) overlies a thin sandstone containing pellets of algal mudstone. A second fault [5935 7480], trending north-east, brings higher beds of sandstone on the northern side against a bed of algoolite (possibly part of M.A.12) on the southern, downthrow, side. Farther upstream is another band of oolite 1 ft thick and associated with flaggy sandstone [5945 7485]; its horizon is uncertain, but it may be M.A.14.

Green's Burn. There are a number of short discontinuous sections in the upper reaches of Green's Burn, between two east-north-easterly faults, both throwing down to the south. The lowest recognizable horizon, the Birky Cleugh Limestone [5850 7398], is represented by 7 ft of limestone with lenses of algoolite 1 ft and 6 ft above the base. It is overlain, after a gap of several feet, by 2 ft of limestone, which appears to be disturbed [5853 7395]. The remaining exposures are given below

	ft
[5862 7391]	
Cementstone (M.A.8), grey shaly	4 to 5
[5868 7389]	
Limestone (M.A.8), grey; nodular algal material near top	10
[5873 7392]	
Limestone	2
Sandstone	5
[5874 7393]	
Limestone (M.A.10), nodular; algal growths encrusting organic nuclei	7½
[5879 7397]	
Limestone (M.A.11), grey	2
Sandstone	—
[5884 7398]	
Shale, grey; a shelly horizon	12
Shale; algal	1
Limestone (M.A.12); compound algal growths investing organic nuclei such as *Orthoceras*	4

Farther south, in a minor tributary, M.A.12 is repeated by faulting as follows [5877 7380]:

	ft
Limestone, grey algal; compound encrusting growths	2
Shale, grey	1½
Limestone, grey shaly; microfossils	2½

White Beck (loc. 27). The upper part of the Main Algal Beds, from the top of the Birky Cleugh Limestone to M.A.4, is exposed continuously in White Beck—a section which is accessible easily from the road. It is given in full in Appendix I (p. 321) and shown graphically in Fig. 13.

The Birky Cleugh Limestone gives rise to a distinctive, broad green tract across the fell north and north-east of Bushley Bank Farm, but only the uppermost 4 ft are exposed in White Beck [5761 7335]: it lies to the north of a small fracture, and apparently is non-algal. Farther up the beck M.A.7 is cut out by a thick sandstone (for petrography see p. 213) and M.A.8 is represented by 1 ft or more of grey limestone [5766 7334]. M.A.9 [5769 7334] is also non-algal, though it is represented by three massive bands of limestone measuring from the base respectively 4½, 4 and 2½ ft and separated by thin bands of mudstone. However, M.A.10 [5775 7333] is more typically algal, consisting of a 6-in band of algoolite at the base, overlain by thin flaggy sandstone and 6½ ft of limestone which includes 2 ft of nodular algal growths. A short unexposed interval separates this limestone from about 5 ft of non-algal cementstone, which is overlain at a bend in the stream by the *Orbiculoidea* Shale [5779 7331]. A few yards upstream [5781 7330] are 7½ ft of nodular algal shale and limestone representing M.A.11. The nodules range in diameter from about 3 to 6 cm and are commonly encrusted with *Spirorbis sp.* About 6 ft higher in the sequence [5783 7327] is M.A.12—Garwood's 'Main Reef'—which consists of at least 3½ ft of grey nodular limestone with algal nodules encrusted with *Spirorbis sp.* '*Collenia*'-type growth-forms also occur, including a specimen figured upside-down by Garwood (1931, pl. xi, fig. 1) and used by Anderson (1950, pp. 20–1) as the basis of his 'White Beck Type'.

M.A.13 [5785 7326] comprises 2 ft of algal shale with abundant nodules of 5 to 20 mm diameter sandwiched between bands of non-algal limestone. The overlying Woodhead Crag Sandstone, which forms low crags on the north bank, displays typical 'curled' bedding, and is at least 10 ft thick in the stream. M.A.14 [5791 7322] comprises 2 to 3 ft of grey limestone which is only doubtfully algal.

The *Orbiculoidea* Shale is further exposed [5761 7301] in a small tributary south-east of Side, and there are several disconnected exposures of algal limestones and shales farther up the same stream as well as in another tributary south-east of Colin Bank.

At least 10 ft of dark limestone, with abundant bivalves, are exposed in an old quarry [5682 7285] between Espy Bank and the earthwork on Towerbrae Cairn: it is probably the Birky Cleugh Limestone.

Ashy Cleugh. Beds above the Birky Cleugh Limestone are exposed at several localities in the headwaters and tributaries of Ashy Cleugh. In the main stream, north of Lady Moss, M.A.8, M.A.9, M.A.10 and M.A.12 can be recognized, but there is little to be seen of measures between the limestones. M.A.8 [5842 7689] consists of 3 to 4 ft of algal limestone in which the internal structure of the nodules is sufficiently well preserved to be seen by the naked eye. M.A.9 is 8 ft thick [5848 7692] and not apparently algal. M.A.10 attains a thickness of 10 ft [5852 7693]. Neither M.A.11 nor the *Orbiculoidea* Shale are exposed, but M.A.12 which is 8 to 9 ft thick and shaly [5861 7692], exhibits the compound nodular algal growths commonly found at this horizon. A north–south branch of the White Preston Fault crosses the stream [5863 7694] and repeats the crop of M.A.10 [5866 7695], which is overlain by the *Orbiculoidea* Shale [5870 7697] exposed in a small tributary draining the ground south of Rushy Crag. A second north–south branch-fault with a small easterly downthrow crosses the main stream [5871 7694] and repeats the crop of the *Orbiculoidea* Shale and associated beds [5880 7693] for some distance north of Black Preston. A varied fauna includes bivalves, dentalids and bellerophontids. The shale is overlain by sandy shales and flaggy sandstone and underlain successively by a thin yellow-weathering ?dolomitic limestone [5884 7692], shales with brachiopods, and algal limestone, which is probably the top of M.A.10 [5895 7693]. The limestone is seen in the bend of the stream and for about 100 yd farther to the north, where it is thrown by the White Preston Fault against measures lying a few feet below M.A.12. A few yards upstream, M.A.12 again crops out [5897 7704] followed by 15 ft of Woodhead Crag Sandstone. The latter forms the western and northern sides of the flat-topped Black Preston Hill and has been quarried [5879 7681].

The White Preston and Antonstown faults form, respectively, the southern and northern margins of a horst structure. Within this structure is White Preston—a smooth conical hill underlain by westerly dipping measures high in the Main Algal Beds. On its northern side, and close to the Antonstown Fault, are the remains of an old (*c*. 1848) exploratory adit from which the many local loose blocks of algal limestone seem to have come. There is extensive calcite veining, but no trace of any other mineralization. About a quarter of a mile to the east, across a wind-gap marking the trace of the Antonstown Fault, is a roughly circular peat-filled hollow [5960 7734], about a quarter of a mile in diameter, and at its centre is a group of sink-holes. Abundant debris, chiefly of algal limestone, indicates that one or more of these caverns was once artificially enlarged, probably in another vain search for lead-zinc minerals.

A small mound of calcite-veined limestone and shale near the head of Ashy Cleugh and directly on the line of the fault [5890 7719] is the only other trace of old mineral workings in this area.

Antonstown Burn and Harepark Cleugh. Main Algal Beds crop out north of the Antonstown Fault in Antonstown Burn and its parallel tributary Harepark Cleugh, but much of the upper part of the sequence is only indifferently exposed. In addition a branch-fault cuts out a considerable thickness of beds in Birky Cleugh.

The lowest Main Algal Beds are well exposed [5729 7759] in Antonstown Burn as follows:

	ft
Sandstone, fine-grained flaggy micaceous	7

	ft
Sandstone, shale partings	2
Shale, dark grey; sandy towards base; bivalves and ostracods	6
M.A.1	
Limestone, oolitic; small algal growths near top and ostracods below	4
Limestone, yellow-weathering; shale partings	1½
Shale	½
Limestone, highly weathered	2
Limestone; ooliths and small algal nodules in top 2 ft; crystalline; ostracods below	4

There may be a fault below this section, for instead of the High Grains Sandstone, thin ostracodal and oolitic limestones crop out.

M.A.2 is seen farther up Antonstown Burn [5738 7761] as follows:

	ft
Sandstone	—
M.A.2	
Limestone, grey crinoidal; shell debris	1
Cementstone, brown; a few ostracods	2½
Limestone, oolitic; *Serpula sp.*	2
Sandstone, shale partings	3

M.A.3 is not exposed in either burn, but M.A.4 crops out in both. In Antonstown Burn [5742 7761] it comprises upwards of 1½ ft of dense algoolite, loose blocks of which contain abundant *Serpula sp.* In Harepark Cleugh [5742 7737] a few yards north of the Antonstown Fault, it is 20 in thick and is overlain by shale and underlain successively by 7 in of shale and 4 ft of brown weathering sandstone.

The following section of the Birky Cleugh Limestone was measured in Antonstown Burn [5747 7761]:

	ft
Limestone, grey yellow-weathering impure	2
Not exposed	2
Limestone, grey; ostracods and a band of small ?algal nodules 1 ft from top	2
Not exposed	2½
Limestone, crystalline; ostracods and rare ooliths; plants at base	1½
Shale, grey; plants	1
Algoolite, grey dense; crystalline at base	1½

Only 3 ft of the limestone are exposed beneath the sandstone in Harepark Cleugh [5747 7737]. The lowest 1 ft contains many small algal nodules. Above it is 1 ft of dense algoolite capped by 1 ft of grey, fine-grained limestone.

The next limestone exposed in upward succession is M.A.8, which in Antonstown Burn [5750 7760] consists of at least 1 ft of dark grey algal limestone with rare ooliths, abundant nodules and '*Collenia*'-type growth forms. This limestone is not exposed in Harepark Cleugh.

A few yards upstream from M.A.8 in the Antonstown Burn are the following [5752 7760]:

	ft
Sandstone, fine-grained current-bedded	4
Shale; calcareous bands; *Antiquatonia teres*	1½
M.A.9	
Limestone, grey crystalline; a few ostracods	3½
Limestone, grey crystalline	4
Limestone, dark grey fine-grained; ostracods and a band of rusty-weathering nodules 1 ft above base	1½

M.A.10 is represented [5756 7761] by a thin band of yellow-weathering cementstone, but there are no exposures of the *Orbiculoidea* Shale or of the beds between and including M.A.11 and M.A.13. M.A.14 crops out, however, in both streams. In Antonstown Burn [5768 7760] it comprises at least 2 ft of partially algoolite cementstone, while in Harepark Cleugh it is represented by a thin grey limestone containing abundant small algal nodules [5759 7737]. At both localities it is overlain by the Lower *Antiquatonia* Band at the base of the Cambeck Beds.

Crew Burn. The Main Algal Beds crop out south of the Black Stantling Fault in that part of Crew Burn known as 'The Linns' and in adjacent tributaries. The lower part of the sequence is almost continuously exposed, but the higher beds are difficult to correlate. The succession is given in detail in Appendix I (p. 281) and shown in graphic form in Fig. 13.

Brackenrow Sike. In Brackenrow Sike M.A.1 [5736 7936] is a thin, yellow-weathering limestone with small '*Osagia*'-type algal nodules; it is overlain by sandstone, locally rooty. The Birky Cleugh Limestone is partially exposed [5754 7926] as follows:

	ft
Limestone, dark grey	1½
Limestone, with shaly partings; ostracods and fragments of *A. teres*	2
Limestone, dark grey	3

A few yards upstream M.A.8 crops out [5756 7924]:

Limestone, grey-blue	1½
Shale, cementstone bands; ostracods and bivalve debris	1½
Limestone; abundant '*Osagia*'-type algal nodules	2 to 3
Sandstone, fine-grained flaggy	3

M.A.9 [5759 7925] is represented by about 9 ft of apparently non-algal limestone, and M.A.10 [5767 7924] consists of at least 7 ft of nodular algal limestone. It is overlain by the *Orbiculoidea* Shale, 3 to 4 ft thick. The overlying beds are not exposed apart from M.A.14 [5776 7916].

White Lyne, north of Brackenrow Sike. Main Algal Beds are exposed intermittently near Shiels Brae and upstream beyond the mouth of Muckle Hare Grain. They cannot be correlated with confidence, and are therefore listed below in upstream order.

	ft
[5687 8030], right bank:	
Shale, with cementstone bands; bivalve debris at top	3
Limestone, grey; rare ooliths	1
Shale, with cementstone bands	2 to 3
Limestone, grey; rare small algal nodules and ooliths	1

[5701 8041], right bank:	
Limestone, blue-grey; shaly bands; ostracods	2
Limestone, grey; ostracods; a band 1½ ft above base contains ooliths	2½
Shale; thin cementstones	about 4
Limestone, grey; a few ostracods	½
Shale, grey; plants	about 4
Sandstone, shaly flaggy; rooty at top	6
Not exposed	4
Shale, calcareous; worm-like markings	¾
Limestone, algoolite; small algal nodules	¾
Limestone, grey; weathers yellow; shaly at base; ostracods	2

	ft
[5751 8047], left bank:	
Shale	—
Limestone, dark grey; ostracods and other fossil debris	1¼
Shale; thin limestone bands; bivalves and a finely ribbed productid fragment	2
Limestone, oolitic; '*Collenia*' and banded structures	1½
Limestone; abundant small algal nodules	1

[5761 8064], both banks:	
Limestone	1½
Sandstone; plant remains	2
Shale	3
Limestone, sandy; fossiliferous	2
Not exposed	7
Sandstone, fine-grained; worm-markings on base	2
Shale	3
Shale, calcareous; ostracods	⅓
Limestone, flaggy; abundant small '*Osagia*'-type algal nodules	1
Sandstone	—

Little and Muckle Hare Grains. The following sections in Little Hare Grain are given in upstream order.

	ft
[5755 8048]:	
Shale, calcareous; ostracods and crinoid debris	2
Limestone, grey fine-grained	2

[5758 8044]:	
Limestone, grey; ostracods at top and small algal nodules below; rare ooliths	2½

[5763 8037]:	
Sandstone, flaggy and shaly	—
Not exposed	8
Shale, grey sandy	2
Limestone, yellow-weathering; ostracods and crinoids	2
Shale; calcareous bands: bivalves and few *A. teres*	4½
Limestone; yellow-weathering; fossil debris	1
Limestone; yellow-weathering; bands of algal nodules	1
Limestone, grey; ostracods	1
Not exposed	2
Limestone, grey; ostracods and a few algal nodules	3

In Muckle Hare Grain (loc. 28), about 200 yd to north-east, an algal limestone, probably at the same horizon as that in the previous section, is exposed as a window [5770 8048]: it contains *Aviculopecten sp.*, *Myalina pernoides* and ostracods. About 250 yd to south-east [5792 8034] a shaly limestone with algal nodules, *Bellerophon sp.* and *Straparollus sp.* s.l. evidently represents M.A.12 or 13, as it is almost immediately overlain by the Woodhead Crag Sandstone.

CAM BECK–KING WATER CATCHMENT

Askerton Low Park. In Askerton Low Park area, along the southern flank of the Bewcastle Anticline, the Main Algal Beds at the core of the fold have undergone much small-scale faulting. Garwood (1931, p. 115) states that the beds are "well exposed in the upper part of Broadfoot [?Broadford] Beck" but exposures seen during the resurvey are poor and difficult to correlate. M.A.1 crops out in an old quarry [5649 7225] where it consists of 3 ft of oolitic serpulid limestone which is faulted against about 12 ft of whitish yellow massive current-bedded fine-grained sandstone. About 220 yd upstream from the quarry, 2 ft of shaly grey limestone overlying 4 ft of algoolite crop out against a fault [5670 7220] and within the next quarter of a mile upstream there are several faulted exposures of limestones and shales. A thin, nodular algal limestone still farther upstream [5715 7209] was thought by Garwood (op. cit., p. 115) to be his 'Main Reef' but it is now thought to lie at a lower level than M.A.12 which is not exposed. A 6-ft limestone may, however, represent M.A.13 [5726 7205]. There is also an exposure of limestone in Melefarm Beck [5582 7188], the section being:

	ft
Limestone, nodular; algal ..	2
Not exposed	10
Limestone; small '*Osagia*'-type algal nodules	6

On Lion's Brae there are many sink-holes, in some of which [e.g. 5653 7178] limestones are exposed. The following section is seen in an old quarry [5667 7168] 550 yd N.W. of Gillalees Farm:

	ft
Limestone, grey	½
Limestone, grey weathered yellow; shelly, rare small algal nodules ..	¼
Limestone, grey shaly	1½
Limestone, grey hard; crinoidal ..	1
Limestone, grey shaly; abundant algal nodules ranging from 1·0 to 10·0 cm in diameter	3
Limestone, massive grey	1¼

Girvanella ducii, *Ortonella sp.* and *Serpula sp.* have been collected from this locality (loc. 26).

An exposure of thin, algal limestone [5710 7142] in a small stream 200 yd N.E. of Gillalees Farm probably represents M.A.12: it is overlain by the Woodhead Crag Sandstone, which crops out in the stream between the previous exposure and the farm.

CAMBECK BEDS

As with the underlying Main Algal Beds, Garwood's (1931) definition of the Cambeck Beds has been retained in this account. They comprise the measures between the base of the Lower *Antiquatonia* Band (Garwood's Upper '*Dictyoclostus*' *teres* Band) and the base of the Whitberry ('*Chonetes*' *cumbriensis*) Band (Fig. 16).

Although there is little change in the lithology of the rhythmically deposited sediments, the fauna of the Cambeck Beds contrasts with that of the underlying measures in being dominantly shelly, thereby seeming to reflect a return to neritic conditions. Algal beds occur at intervals throughout the sequence, but few are as well developed as those below. There is an abrupt change from the earlier, dominantly algal, lithology at the base of the Lower *Antiquatonia* Band. This consists of 90 to 100 ft of alternating calcareous shales and thin limestones in which many of the bedding planes are packed with *Antiquatonia teres*, locally

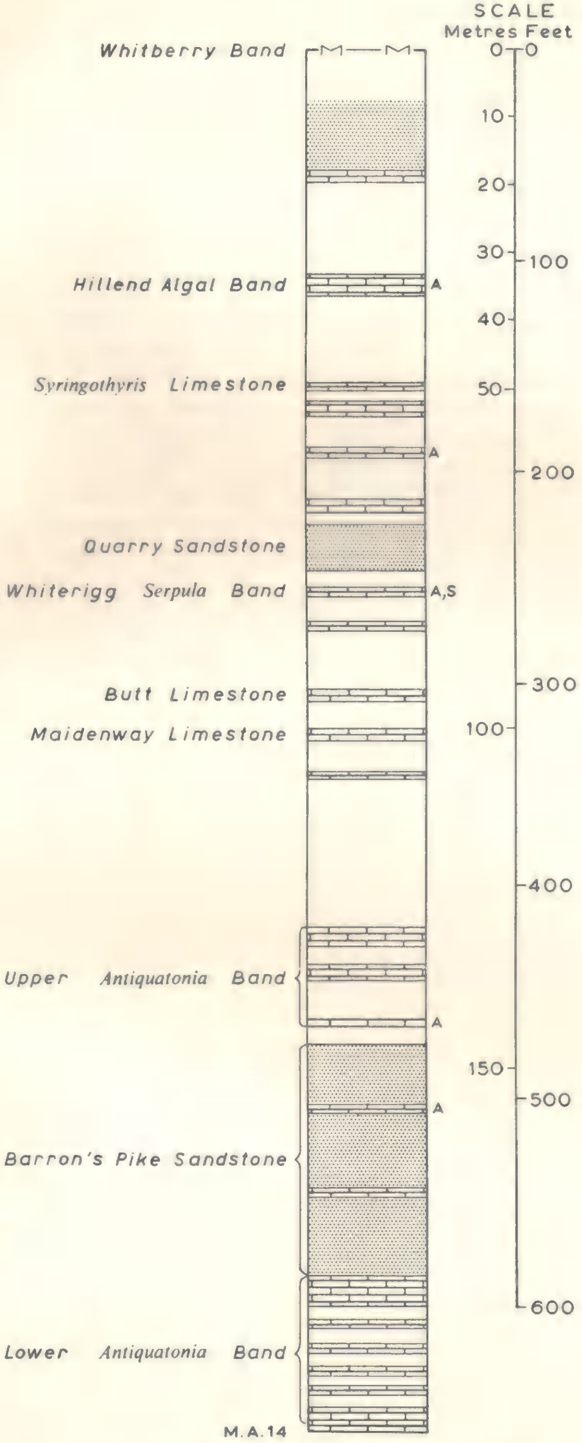


FIG. 16. *Generalized vertical section of the Cambeck Beds. For key see Fig. 5*

almost to the exclusion of other species such as *Cleiothyridina glabristria* and *Schuchertella ambigua*. The shales are overlain by the thick Barron's Pike Sandstone consisting of two, or more commonly three, massive false-bedded 'posts' separated by thin beds of shale, some of which include thin algal limestones. The sandstone is succeeded by the Upper *Antiquatonia* Band—up to 40 ft thick, and lithologically similar to the lower band. *A. teres* is abundant throughout, and the remainder of the fauna also is similar to that of the Lower *Antiquatonia* Band except for the addition of *Syringothyris exoleta* which first appears at this horizon contrary to Garwood's (1931, p. 112) statement that this form (which he records as *S. cuspidata*) first occurs below in his 'Upper "*D.*" *teres* Band'.

The succeeding strata consist of rhythmically deposited sandstones, shales and thin, shelly, massive or algal limestones. Towards the top of the sequence the *Syringothyris* Limestone, comprising a single bed or, locally, a group of thin limestones, is easily identified by an abundance of well-preserved *S. exoleta* and *Schuchertella ambigua*. It forms a useful marker, particularly in the fells north of Bewcastle and in the Spadeadam area, but it has not been found in the River White Lyne. The Hillend Algal Band can be distinguished in several, though not all, of the sequences through the overlying measures. It is particularly well developed in Cam Beck, Whitberry Burn and the River White Lyne.

The Cambeck Beds are well exposed in the southern part of the district, particularly in those areas north-east of Kirkcambeck drained by the Cam Beck and its tributaries. However, the most complete section, measuring 670 ft, is exposed in Whitberry Burn on the steeply dipping western limb of the Bewcastle Anticline. A comparable, but reddened, section is exposed in the River White Lyne north of Kaysbank. East of Bewcastle village, Cambeck Beds cap the fells and form gentle, drift-covered dip slopes inclined into the Irthing catchment. North of the Antonstown Fault their outcrop is shifted westwards to form the middle slopes; in this area there is evidence that the Cambeck Beds become progressively more sandy towards the north. In the western part of the district the lower measures of the division are exposed in Crook Burn, whilst in the Kershope Burn at Kershopefoot measures believed to be of Cambeck age include algal bands such as the Kershopefoot Limestone and underlie massive sandstones of the Middle Border Group.

Cambeck Beds: Details

KERSHOPE BURN AND LIDDEL CATCHMENTS

Measures referable to the Cambeck Beds because they contain *Athyris glabristria* and underlie sandstones of Middle Border age, are exposed intermittently in the Kershope Burn for about 500 yd upstream from its mouth (loc. 30). The lowest bed [4759 8294] is a thin bluish grey sparsely nodular algal limestone; it is overlain by several feet of rooty sandstone with calcareous bands. There is an unexposed interval between the sandstone and the following beds which crop out in the left bank of the stream [4764 8292] at a bend:

	ft
Limestone	—
Shale, blue-grey calcareous; algal nodules, crinoid debris, and *Ovatia bioni*	1
Shale, grey sandy micaceous ..	1
Limestone, blue fine-grained, hard sandy partings; algal nodules ..	4
Limestone, brown hard fine-grained; algal nodules	1

These beds lie on the strike of the Kershopefoot Limestone exposed in the Station Quarry; [4750 8280]; (loc. 31) from which

Nicholson (1888) obtained his specimens of '*Mitcheldeania*' *gregaria;* this horizon was taken by the original surveyors to mark the summit of the old 'Cementstone Group' and by Garwood (op. cit., p. 127) to represent the highest algal limestone in the Cambeck Beds. As Garwood found, the section in the quarry is largely overgrown, but part of it can still be seen near the north end:

	ft
Limestone, grey rubbly; fossiliferous at base; *Ovatia bioni* and smooth spiriferoid indet.	1
Shale, dark grey	1¼
Limestone, blue-grey brown weathering fine-grained	2
Shale	1
Limestone, blue fine-grained; algal nodules and microfossils in shaly bands	3¾
Shale, grey calcareous; fossiliferous	1¼
Limestone, grey hard fine-grained	1

Garwood (op. cit., p. 127) records *Athyris glabristria* from this quarry. This species was not obtained during the resurvey, but it was seen (though not collected) at a slightly higher horizon in a thin crinoidal limestone exposed in the bed of Kershope Burn [4773 8296].

Higher beds are obscured for about 140 yd upstream, above which the following sequence is exposed [4787 8297]:

	ft
Sandstone, light grey brown-weathering medium-grained calcareous; *Antiquatonia teres* and smooth spiriferid fragments	1
Limestone, impure brown earthy; weathering to rottenstone; brachiopods	2
Not exposed	—
Sandstone, calcareous; a band of crystalline limestone	2½
Limestone; abundant productids and algoolitic patches	1¼
Sandstone; roots	½
Limestone, impure	2
Sandstone, flaggy	½
Shale	1¾
Limestone, impure; *A. teres* ..	½
Shales with thin limestone bands; shell debris	3½
Not exposed	3
Limestone; algoolitic at top, crinoid debris below; smooth spiriferids indet.	6
Sandstone, white; roots	1

About 50 ft above the top of this section a crystalline fossiliferous limestone is associated with grey calcareous shale [4789 8290]. It is overlain by calcareous sandstone containing worm tracks and representing the highest horizon locally exposed in the Cambeck Beds, for about 30 yd upstream there is a fault throwing down Middle Border Group sandstone on its eastern side.

Exposures at two localities in the Liddel Water between the Kershopefoot Fault and the mouth of the Kershope Burn are believed to be of Cambeck Beds or, less likely, Main Algal Beds. One lies just south of Kerr Pool in the Scottish bank [4701 8215], and is described by Lumsden and others (1967, p. 87); it consists of a southerly-dipping sandstone, shales and oolitic limestones. The other lies in the English bank at Barn Pool [4742 8282] and is cut by a northerly fault. East of the fault the strata, dipping westwards at 80°, are as follows:

	ft
Limestone, grey rubbly (against fault)	3
Shale, grey-blue	1
Limestone, blue-grey algoolitic ..	1½
Limestone, grey weathered brown fine-grained	4¾
Not exposed	3
Limestone, grey fine-grained with black partings; rare plant remains	3
Not exposed	3
Limestone, brownish grey fine-grained; rare algal material ..	2

West of the fault the following measures dip east at 30°:

	ft
Limestone, blue-grey brown-weathering fine-grained; algoolitic band near top and ?algal pellet bands throughout	8
Not exposed	20 to 30
Limestone, grey-blue; algal and algoolitic bands [4741 8280] ..	6
Sandstone, light grey medium-grained flaggy	2
Limestone, weathered brown; sandy at base	2½
Sandstone, medium-grained weathered brown; plant debris ..	2

The lowest horizon, exposed in the bed of the stream about 20 yd farther west, is 1 ft of ?algal limestone.

LYNE CATCHMENT

Kirk Burn. Cambeck Beds crop out in Kirk Burn on both flanks of the Stapleton Anticline. On the eastern flank the lowest beds can be seen overlying the Main Algal Beds described on p. 47; they consist of about 15 ft of calcareous shales with thin limestone ribs containing *A. teres* [5041 7107] and they represent the lower part of the Lower *Antiquatonia* Band. Higher members of the band, farther upstream, consist of limestones up to 6 ft thick, most of them containing fragments of *A. teres* and bivalves. The top of the band is marked by 1 ft of sparsely crinoidal limestone exposed in the left bank [5052 7107]. The beds are reddened, and dip to the south-east at angles varying between 30° and 40°. The overlying Barron's Pike Sandstone is not exposed.

The rocks of the western flank of the anticline are mainly covered by drift, apart from a sandstone cropping out [5003 7102] south-west of Stapleton church, and a thin bed of reddened limestone at a sharp bend in the stream [4990 7114]. A small runnel joining the burn from the north at this bend is crossed by the Kaysbank Fault, and on the western, downthrow, side of the fault are 24 ft of vertical reddened shales and limestone striking north-east. The shales are calcareous and contain a fauna dominated by bivalves, with rare brachiopods. These beds are probably of Cambeck age, as the displacement of the Kaysbank Fault is believed to be small at this locality.

BLACK LYNE CATCHMENT

River Black Lyne. The Lower *Antiquatonia* Band crops out in the headwaters of the River Black Lyne just above the junction with Lancy's Cleugh, and also forms a strike-section in Lancy's Cleugh itself. Altogether about 30 to 35 ft of grey calcareous shales alternating with bands of grey limestone are exposed, *A. teres* being common throughout.

The Lewisburn Dyke crosses Lancy's Cleugh about a quarter of a mile upstream from its mouth; it is 23 yd wide and follows the line of an east–west fault which has a southerly downthrow of 8 to 10 ft. At the southern contact of the dyke the lower 3 ft of the Barron's Pike Sandstone is white, brittle and shattered, and overlies 6 ft of white baked fossiliferous shale, with thin limestone bands which have undergone secondary alteration for a distance of 5 to 6 yd from the contact. On the northern side of the dyke, the Barron's Pike Sandstone is at least 14 ft thick in the north bank. Beneath it is an unexposed interval of about 20 ft extending down to 10 ft of altered limestone which crops out in the bed of the stream. The upper part of the limestone contains shale partings, but the lower part is crystalline and contains abundant *A. teres*. The alteration extends as far as the limit of exposure, 10 yd upstream from the dyke, and slight induration is still apparent at the next exposure — a limestone cropping out on the left bank [5554 8481], 20 yd from the dyke. Farther upstream the lowermost beds of the Barron's Pike Sandstone can be seen.

Between the north-north-easterly East Skelton Fault and the River Black Lyne, sandstones in the Cambeck Beds form features round the western side of the valley particularly between Davy's Round and Watt's Sike. The highest of these is Tod Crag—a typical 'felsenmeer' or boulder-slope formed by boulders of sandstone which are either white and fine-grained or weathered brown and medium-grained with calcareous cement and rare shell-casts. West of Tod Crag and of the East Skelton Fault are a set of limestone features marked by lines of sink-holes through thin hill-peat. They lie at a high level near the crest of a flattish spur forming the divide between the Black Lyne and Bailey Water catchments. The ground from here to Skelton Pike, farther south, is also probably underlain by Cambeck Beds.

The Lower *Antiquatonia* Band is repeated in the River Black Lyne by the Bellevue Fault. It is represented in the river bed [5440 8132] south-south-west of Black Lyne House by 2 ft of grey ostracodal limestone, and in the right bank, beyond the alluvium, by a lower 1-ft limestone containing ostracods and brachiopod spines, and an upper 2½-ft flaggy limestone with *A. teres*. These limestones are overlain in Clints Sike by the lower part of the Barron's Pike Sandstone which includes a 1¾-ft algal limestone [5430 8133].

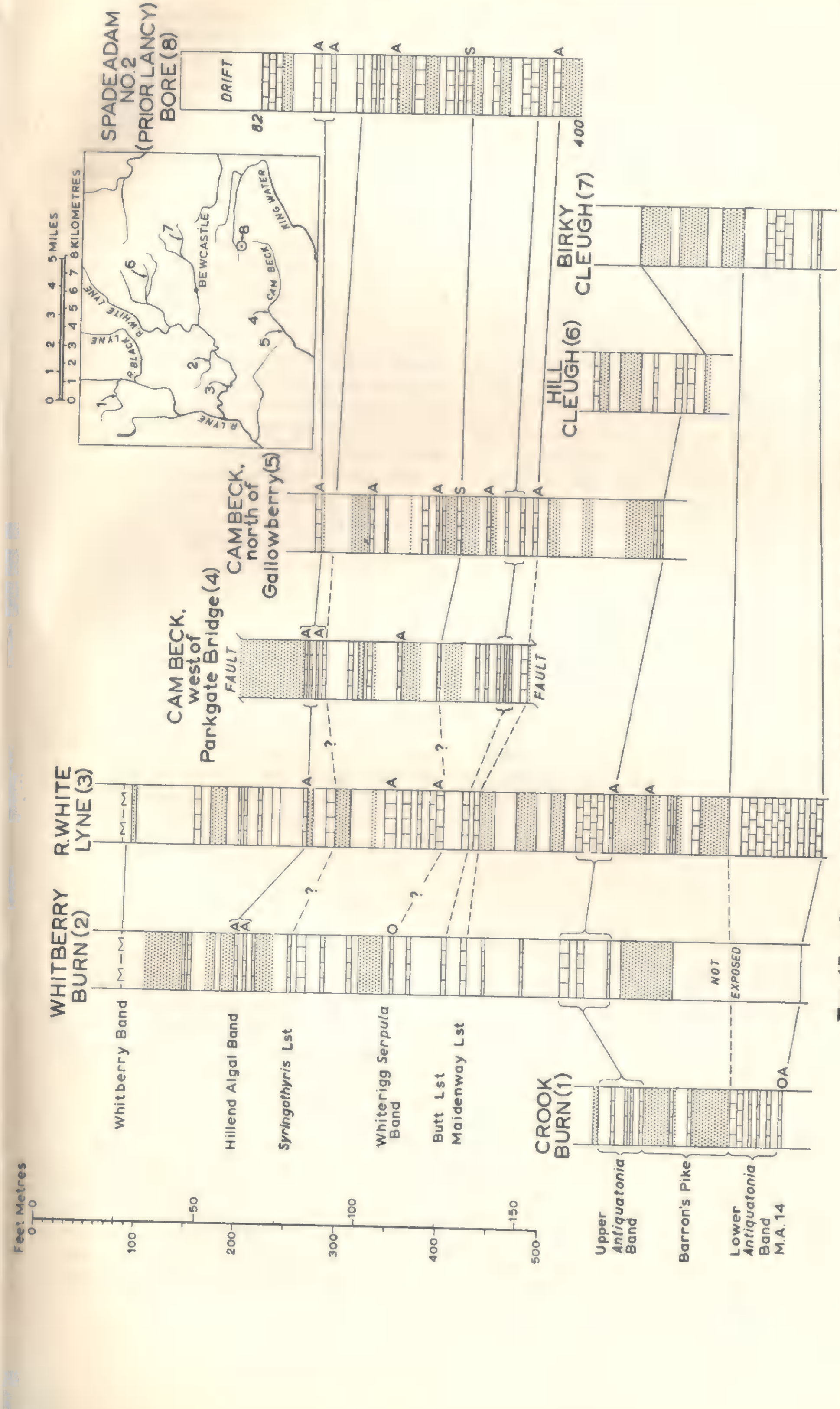


FIG. 17. *Comparative vertical sections of the Cambeck Beds. For key see Fig. 5*

The Barron's Pike Sandstone is cut off farther up the sike by the Bellevue Fault [5424 8130], but it continues south-south-westwards as a distinctive feature on the valley side. It forms part of the eastern limb of a north-north-easterly syncline, and may be equivalent to poorly exposed sandstones [5282 7970] dipping eastwards on the opposite limb.

The Beck. About 2 ft of limestone and shale forming part of the Lower *Antiquatonia* Band crop out [5705 8291] in The Beck. The overlying Barron's Pike Sandstone, which is massive, current-bedded, fine-grained and graded, forms a deep, boulder-strewn gorge and waterfall a short distance north of the Beckhead–Binky Linn Fault. About 80 yd farther upstream this fault cuts the corner of the stream at its confluence [5723 8297] with a small tributary entering from the south-east, and Middle Border Group sandstones are thrown down on its southern side against vertical shaly grey limestone striking into the fault-plane from the north. The higher reaches of The Beck follow the fault so that only the strata on the northern side belong to the Cambeck Beds. Most of these are sandstones, but one faulted section [5738 8308] includes a thin ?algal limestone with ostracods and two limestones containing crinoid debris, while another section [5746 8311] shows the *Syringothyris* Limestone to consist of 6 in of grey cementstone overlain by 13 in of limestone with shale partings, and with *Syringothyris sp.* and *Schuchertella sp.* beneath a shale roof.

Bailey Water. Strata believed to belong to the Cambeck Beds crop out west of the Cuddy's Fault in a small tributary which rises near Coldside. The section, which dips steeply towards the fault, is as follows [5175 7886]:

	ft
Shale	—
Limestone, nodular; algal ..	2
Limestone, grey fine-grained ..	¼
Sandstone, medium-grained current bedded	—

Lower down the stream is a thin dolomitized limestone [5174 7889].

Crook Burn (loc. 32). The lowest 200 ft of Cambeck Beds including the Lower and Upper *Antiquatonia* bands with the intervening Barron's Pike Sandstone are exposed in Crook Burn near Crookburn Farm, where they form part of a long continuous sequence given in detail in Appendix I (p. 283) and shown graphically in Fig. 17.

The Lower *Antiquatonia* Band is at least 50 ft thick and consists typically of shelly shales with thin limestone ribs. It crops out immediately south-west of the farm and is succeeded by the Barron's Pike Sandstone, in all 80 to 90 ft thick, but incompletely exposed. The sandstone is shaly towards the top, and includes at least two limestones, the lower being 3 ft thick. The overlying Upper *Antiquatonia* Band, about 40 ft thick, gives rise to a series of strike sections south and east of the farm. The lithology and fauna are very similar to those of the Lower *Antiquatonia* Band except for *Syringothyris exoleta* which makes its first appearance in the upper band.

WHITE LYNE CATCHMENT

Whitberry Burn (loc. 33). The beds exposed in Whitberry Burn form part of the steeply dipping western limb of the Bewcastle Anticline east of the Lyneholmeford Fault-belt. The section commences in the Main Algal Beds at the Birky Cleugh horizon, continues upwards through Cambeck Beds into measures of Middle Border age. It is given in detail in Appendix I (p. 319) and graphically in Fig. 17. The total thickness of Cambeck Beds in this section is about 670 ft, but this includes an unexposed interval of 130 ft at the base of the section, in which neither the Lower *Antiquatonia* Band nor the lower part of the Barron's Pike Sandstone are exposed. The remainder of the sandstone is about 50 ft thick (for petrography see p. 213) and includes 1 ft of dark calcareous shale [5220 7404] with sparse '*Osagia*'-type algal nodules, equivalent to the more conspicuous algal limestone at this horizon in the River White Lyne (p. 73). The Upper *Antiquatonia* Band is exposed in the right bank [5218 7405] almost due south of Hillend, and poorly-developed equivalents of the Maidenway and Butt limestones of the Spadeadam area (p. 77) are exposed 40 and 50 yd respectively upstream from this locality. The succeeding 150 ft of strata include several thin limestones, some of which yield faunas dominated by bivalves. The most important band, however, is the *Syringothyris* Limestone ('*Syringothyris*-

Derbyia Band' of Garwood) exposed in the stream [5208 7408] 180 yd S.W. of Hillend barn. It consists of 3½ ft of hard, crystalline limestone crowded with excellent specimens of *S. exoleta* and *Schuchertella ambigua.* About 15 yd farther upstream is the Hillend Algal Band consisting of 1 ft 2 in of nodular algal limestone. It is succeeded, after a 4-ft unexposed interval, by 1 ft of nodular algal shale. Algal species collected from this band include *Aphralysia sp.*, *Girvanella amplifurcata*, *G. wetheredii*, *Ortonella furcata*, *O. kershopensis* and *O. tenuissima.*

About 45 ft higher in the sequence are 3 ft 8 in of sparsely oolitic, possibly algal limestone separated by 3½ ft of shale from a higher limestone 2½ ft thick. The latter is overlain by more than 30 ft of massive sandstone [5206 7409], separated by an unexposed interval of about 18 ft from several feet of sandy shale (for petrography see p. 213) which appear to be affected by a minor fault. This shale grades upward into the highly fossiliferous calcareous shale of the Whitberry Band [5203 7408], (p. 92) at the base of the overlying Middle Border Group.

River White Lyne (loc. 34). Cambeck Beds are exposed in the River White Lyne (Fig. 17) as part of a continuous nearly vertical sequence which extends from the Main Algal Beds at the base almost to the top of the Upper Border Group and which is given in detail in Appendix I (p. 312). The Lower *Antiquatonia* Band, consisting mostly of pink shaly limestone, is about 100 ft thick in the river [5116 7300], 130 yd N.E. of Kaysbank Farm, but much of it is beneath water level. All three posts of the Barron's Pike Sandstone can be distinguished: the bottom post is overlain by 8 ft of pinkish crinoidal limestone [5116 7303], the middle post is shaly and split by two thin bands of limestone, and the upper post lies between bands of markedly nodular, reddened algal limestone.

The Upper *Antiquatonia* Band of this section was exposed during the resurvey in the left bank [5114 7309] below a low overhanging cliff, but the latter subsequently has collapsed. The limestones are terminated at the water's edge by a west-north-westerly dextral strike-slip fault which displaces them laterally by 90 ft to the opposite bank, where only debris can be seen.

The succeeding measures including at least two algal beds [5113 7315], are affected by several minor tear-faults, but differences in the lithology of the two algal beds serve to avoid confusion. The lower bed consists of 1½ ft of algal limestone sandwiched between two non-algal limestones overlying red shale, whereas the upper bed comprises 2½ ft of nodular algal limestone resting on 9½ ft of non-algal limestone which in turn immediately overlies a distinctive brick-red white-flecked sandstone.

The *Syringothyris* Limestone is not known with certainty in this section, but it may be represented by 12 ft of marly, pink limestone [5112 7318], the top of which is not exposed. However, the Hillend Algal Band, which overlies the *Syringothyris* Limestone in the Whitberry Burn sequence, was recognized [5111 7319].

The succeeding 130 ft of beds do not merit special mention, but they are followed by about 50 ft of red shales and marls with several fossiliferous bands. At the base, and at a higher level, they contain *Sanguinolites sp.* (*tricostatus* group), and between 25 and 35 ft above the base *Syringothyris sp.* is fairly common. The occurrence of *Punctospirifer scabricosta* in a band 25 ft above the base is unusually low; only at two other localities in the district (p. 79) has this species been found within the Lower Border Group. The thick shale is separated by 7 to 8 ft of purplish sandstone from a higher 25-ft bed of similar shale [5109 7322], from near the base of which a single specimen of *Chonetes*? s.l. has been obtained. For want of more positive evidence, the base of this upper shale has been taken to represent the Whitberry Band at the base of the Middle Border Group. It is nevertheless possible that the band may be equated with the base of the lower shale, for both shales together form a thick argillaceous sequence similar to that overlying the Whitberry Band in Whitberry Burn.

Show Burn (loc. 35.) Cambeck Beds are exposed discontinuously in Show Burn over a distance of half a mile upstream from a locality 75 yd S.W. of Low Floweryhirst Farm, where they form part of the gently-dipping eastern limb of the Bewcastle Anticline and are all deeply reddened. The lowest exposed beds appear to lie above the level of the Lower *Antiquatonia* Band and are as follows:

	ft
Sandstone, red [5251 7218] ..	4
Shale, red	1½
Sandstone, reddish mottled rooty	2

	ft
Limestone and red shale in alternating bands	12
Not exposed	6
Shales, red; limestone nodules	4
Sandstone flags, micaceous	6
Not exposed	12
Limestone, red and grey; in bands [5249 7221]	7

Higher beds crop out upstream. Floweryhirst bridge [5261 7219] is founded on a thin flaggy crinoidal limestone, and just east of the bridge is an outcrop of shelly calcareous shale with abundant bivalves including *Myalina sp.* and *Sanguinolites sp.* About 25 yd east of the bridge the stream is crossed by a small north–south fault beyond which are two 2½-ft red nodular algal limestones lying a few feet apart and cut off to the east by a south-easterly fault [5268 7215]. These limestones (loc. 35a) have yielded *Garwoodia gregaria*, *Girvanella amplifurcata*?, *G. ducii*, *G. staminea*, *Koninckopora inflata*, *Ortonella furcata*, and *O. kershopensis*.

Seven more thin red limestones, some crinoidal and some associated with shelly calcareous shales, crop out over a distance of 250 yd upstream from the south-westerly fault. The *Syringothyris* Limestone cannot be recognized among them, though a short distance upstream [5316 7199] a nodular algal red limestone 4 ft thick and containing (loc. 35b) *Girvanella ducii*, *Koninckopora inflata* and *Ortonella furcata* probably represents the Hillend Algal Band. Another thin, nodular algal limestone cropping out 40 yd farther east is equivalent to the limestone which occurs about 60 to 65 ft below the Whitberry Band in the type section (p. 73). This algal limestone is succeeded first by sandstone and shale [5321 7195], then by the Whitberry Band [5325 7194].

Farther upstream the Cambeck Beds are repeated by the Show Burn Fault, but exposures are poor except for the shales immediately underlying the Whitberry Band [5383 7201; loc. 35c] which have yielded *Schuchertella ambigua*.

Tributaries of the Kirk Beck. The Lower *Antiquatonia* Band is well exposed in the headwaters of several of the Kirk Beck tributaries, notably the north-eastern branch of White Beck and Birky and Bull cleughs. The outcrop of the band on the fellside forms a broad green belt with rows of sink-holes lying between the distinctive features of the Woodhead Crag and Barron's Pike sandstones. The shelly limestones within the band show marked lateral variation, so that no two sequences are similar in detail. In White Beck the exposed thickness of the band is 85 ft with no single limestone exceeding 7 ft in thickness; whereas in Birky Cleugh the band, altogether 90 to 100 ft thick and repeated by faulting [5937 7539 and 5944 7540], includes a 25-ft shaly flaggy limestone in which *A. teres* is abundant. Many species were collected from the basal shales at the ford [5932 7539] in Birky Cleugh (loc. 36).

In Bull Cleugh the Lower *Antiquatonia* Band is almost horizontal and is exposed continuously from a locality [5920 7633], north of Green Brae for about half a mile upstream, past Bullcleugh Gate. The band is 80 to 90 ft thick and as at Birky Cleugh, parts of it are repeated by faults [5930 7649 and 5956 7667].

The overlying Barron's Pike Sandstone, probably about 100 ft thick, caps the fells in the area between Side Fell and Bottle Crag where it dips gently to the east and locally emerges through the peat in a series of subparallel crags. The most prominent are Barron's Pike and Hazelgill Crag, at both of which the sandstone contains the contorted type of current-bedding typical of the Northumbrian Fell Sandstone and previously noted (p. 46) in the older Woodhead Crag Sandstone. On the faces of both Hazelgill Crag and Barron's Pike, weathering processes have sculpted wind patterns which seem to have been mistaken for runic inscriptions. As elsewhere, the three constituent posts appear to be separated by thin bands of shale, each of which may include a limestone, but only one is exposed—in the headwaters of Birky Cleugh [5960 7553].

North of the Antonstown Fault. Around White Preston, north of the Antonstown Fault, the Cambeck Beds form the middle slopes, on which long continuous stream sections are rare apart from the following in Hill Cleugh [5780 7719].

	ft
Shale; bivalves and common, minute turbinate gastropods	7
Limestone, earthy; crinoidal	1¾ to 2
Shale, sandy	2⅓
Sandstone, flaggy	5
Not exposed apart from shale debris	2 to 3
Shale, sandy; sandstone bands	12
Limestone	½

	ft
Sandstone, flaggy	2
Sandstone, massive	2¾
Sandstone, flaggy shaly	3½
Sandstone, massive; forming waterfall; flaggy towards base ..	10 to 12
Not exposed	7
UPPER *Antiquatonia* BAND	
Shale, slightly sandy	4 to 5
Shale, flaggy calcareous, shelly courses containing bivalves and brachiopods including rare *Syringothyris exoleta*	5
Shale, calcareous; thin shelly limestone bands; *A. teres* abundant and a single specimen of *S. exoleta*	18 to 20
Limestone, shaly towards top; shelly, crinoidal	5¼
Shale, calcareous sandy; rare plant debris at top, and bivalves below	6
Limestone, earthy; rare shells ..	3⅔
Shale, calcareous; *Aviculopecten sp.*, *Edmondia sp.*, *Sanguinolites sp.* and dentaliids; *Orbiculoidea nitida* common in a thin band 2½ ft above base..	4
BARRON'S PIKE SANDSTONE	
Shale, sandy; sandstone bands	9 to 10
Sandstone, massive; slightly disturbed	12 to 15

The Lower *Antiquatonia* Band, faulted out of the previous section, is partially exposed in Harepark Cleugh [5762 7737] and Antonstown Burn [5771 7760]. In the former it is no more than 65 ft thick; in the latter it is represented by 30 to 35 ft of shelly shales, and although there are unexposed intervals, the total thickness of the band seems nevertheless thinner than to the south. Part of the Upper *Antiquatonia* Band is exposed in Antonstown Burn [5794 7765].

About half a mile to the north, between Whiteside End and the Black Stantling Fault, the Barron's Pike Sandstone gives rise to a characteristic triple-tiered feature, but is not well exposed. Parallel features such as Crew Crag are formed by massive sandstones higher in the succession, but there is little to be seen of the intervening beds apart from a few feet of sandy shale with abundant ostracods [5805 7775].

Farther to the north-east, Crew Burn drains a lens-shaped fault-block at the western end of which the Barron's Pike Sandstone is folded into a gentle syncline with a complementary anticline. The uppermost 27 ft of the Lower *Antiquatonia* Band [5732 7855] are followed by the lower leaf of the Barron's Pike Sandstone, about 30 ft thick, in turn overlain by:

	ft
Shale; bivalves and ostracods ..	3
Limestone, grey impure; rare crinoidal debris, and abundant bivalves and ostracods towards top ..	3¾
Shale; thin limestone bands ..	6

This sequence is seen best in a window produced by the folding [5746 7856] and is also visible downstream [5737 7855] where it is overlain by the 30-ft upper leaf of the Barron's Pike Sandstone.

The limestone is probably the lower of the two usually found within the sandstone, the upper being absent locally. Still farther upstream the Upper *Antiquatonia* Band [5763 7859] is represented by shelly shales with *A. teres*, and the following sequence at a higher level is exposed about 70 yd to the east:

	ft
Sandstone	—
Shale, grey	7
Limestone; small '*Osagia*'-type algal nodules	2

The sandstone forms Crew Crag, south of the Black Stantling Fault. North of the fault it forms a prominent feature which includes Sockles Stell and, still farther north, Brunt Crag. Above it in Whams Sike is an exposure (loc. 37) of the *Syringothyris* Limestone [5799 7863] consisting of limestone with thin bands crowded with *S. exoleta* and *Schuchertella ambigua*. At a higher horizon, a few yards up the sike, is a bed of limestone in which *Edmondia* is common [5801 7865] and this is overlain by sandstone.

In Brackenrow Sike the Lower *Antiquatonia* Band [5780 7915] is not more than 75 ft thick; it appears to be slightly thinner in Muckle Hare Grain, and is no more than 40 to 50 ft thick in the River White Lyne, where it is incompletely exposed along the strike [5786 8073]. The Barron's Pike Sandstone crops out both in the river and in Muckle Hare Grain, but the Upper *Antiquatonia* Band is only partly exposed in the river, around the junction of Gate and Rough grains [5830 8099]. Higher beds are exposed in Muckle Hare Grain as follows:

[5824 8032; loc. 38a]	ft
Sandstone	—

Shale, grey sandy	3
Limestone, grey earthy; algal growths and ostracods	1½
Mudstone; plants	1
Fireclay, with coaly streaks ..	1½
Not exposed	4
Mudstone, grey-brown shaly; *Eocaudina scotica*, *Orbiculoidea sp.*, *Spirifer sp.*, *Plagioglypta sp.*, bivalves and ostracods including *Hollinella sp.*	2
Limestone; *A. teres*, *Lingula sp.* and *Aviculopecten sp.*	⅔
Mudstone, grey	2
Limestone, grey; *Eumetria sp. nov.*, *Schuchertella ambigua* and *Syringothyris sp.*	3
Mudstone; *Orbiculoidea sp.* and ostracods	3
Mudstone, shaly; *Lingula sp.*, *Orbiculoidea sp.*, *Aviculopecten sp.*, *Myalina sp.*, *Pteronites latus* and ostracods	½
Limestone, earthy; *Schizodus sp.* and ostracods	2½
Mudstone; *Aviculopecten sp.* and ostracods	¾
Limestone, earthy	1
Mudstone; *Aviculopecten sp.*, *Sanguinolites sp.* and ostracods including *Paraparchites sp.*	1
Limestone, earthy	1½

This section lies several hundred feet below the *Syringothyris* Limestone of Whitberry Burn and may be the equivalent of the band just above the Butt Limestone in the Cam Beck west of Parkgate Bridge (p. 79). In Muckle Hare Grain the band with *Syringothyris* extends for about 30 to 40 yd upstream and slightly higher beds crop out [5833 8034; loc. 38b] immediately west of the Rough Grain Fault as follows:

	ft
Mudstone, grey shaly; small algal nodules 10 in from top and turreted gastropods, *Schizodus sp.* and indet. bivalves 1 ft from top	4
Limestone; *Aviculopecten sp.* and other bivalves	¼
Mudstone, grey shaly	3½
Limestone, grey earthy; rare *Syringothyris exoleta* ..	6
Not exposed	8
Mudstone, grey; *Aviculopecten sp.* and other bivalves	4
Not exposed	2
Shale, earthy; crinoid debris and ostracods	3

The Rough Grain Fault cuts out about 200 ft of strata. On the south-eastern (downthrow) side there are about 12 ft of grey, barren shale [5836 8034], and higher there is sandy mudstone and weathered, ochreous calcareous material [5845 8029] which must lie very near the top of the Cambeck Beds, as the Whitberry Band is exposed a few yards upstream [5850 8027].

Strata higher than the Upper *Antiquatonia* Band form discontinuous sections in Gate and Rough grains. About 110 yd north of the confluence of these streams there is an exposure of thin, yellow-weathering algoolitic limestone overlain upstream by sandstone and a second yellow-weathering limestone [5831 8110; loc. 39], about 3 ft thick, which has yielded *Antiquatonia teres*, *Orbiculoidea nitida*, *Aviculopecten sp.* and other bivalves. A nodular algal calcareous sandstone crops out [5837 8125] about 150 yd upstream, but farther north most of the solid rocks are masked by large sandstone boulders detached from the Middle Border Group crags.

In Rough Grain exposures are mostly of sandstone, including the algal sandstone [5870 8104] seen in Gate Grain. Higher in the sequence [5875 8105] limestones are present as follows:

	ft
Limestone, grey impure; shaly partings; ostracods and a band crowded with crinoid debris at top [5878 8106]	4
Limestone, impure and calcareous shale; bivalves and ostracods ..	½
Shale, weathered brown; *Orbiculoidea sp.*, at base	1½
Shale, blue	1
Not exposed	—
Sandstone, weathered brown, current-bedded partly calcareous; roots at top	4
Limestone, algoolitic; ostracods ..	¼
Limestone, crowded with ostracods	1
Limestone, shaly; rare ostracods [5875 8105]	1

The uppermost stream the Cambeck Beds are exposed in the north bank [5878 8107; loc. 40] where the Whitberry Band (p. 93) is underlain successively by 6 ft of apparently unfossiliferous brown mudstone and by 12 ft of brown shaly mudstone with plates of *Archaeocidaris sp.*, *Fenestella* *sp.*, *A. teres*, *Lingula sp.*, *Spiriferellina sp.*, bivalves and ostracods.

Between the East Christianbury and Beckhead–Binky Linn faults. Exposures of solid rocks are few in the tract of country which straddles the divide between the White and Black Lyne catchments. Disconnected outcrops in Ellery Grain consist mainly of sandstones, some calcareous, but which also include 1 ft of fine algal breccia [5660 8024] and 1 ft of algoolitic limestone with small '*Osagia*'-type nodules [5658 8029]. Across the divide, two thin algoolites are exposed [5551 8161 and 5564 8158] in Kettle Sike, and a third is seen [5557 8171] in a small tributary entering from the north.

CAM BECK–KING WATER CATCHMENT

The catchment of the Cam Beck and its tributaries east of the Low Park Fault is underlain almost exclusively by Cambeck Beds. Although there are good continuous stream sections, none completely spans the full thickness of the beds. The best sequence is provided by the Priorlancy Borehole [5910 7192] (Appendix II, p. 331; loc. 41; and Fig. 17).

The Lower *Antiquatonia* Band is 80 to 100 ft thick at outcrop in Kettle Beck and in the unnamed stream which flows southwards between Mollin Wood and Gillalees Scroggs. As in the area farther north, it consists of alternations of shale and thin shelly limestones commonly crowded with *A. teres* and other fossils. In Melefarm Beck [5552 7171] 10 to 11 ft of shelly limestone and shale lie near the base of the band. The overlying Barron's Pike Sandstone locally consists of two thick massive posts separated by thin shales and a limestone. The lower post has been quarried [5732 7140] on the flanks of The Beacon east of the Shopford Fault and its petrography is described on p. 213. West of the fault the lower post forms Gillalees Scroggs, east of the Bewcastle road, and wooded crags up to 35 ft high [5607 7102]. Crags in Mollin Wood [5615 7084, 5625 7079] are formed by the upper post. The limestone between the posts is exposed [5730 7074] in a small runnel which enters the Cam Beck from the north almost ½ mile S.S.E. of Gillalees Farm, and again in the stream [5637 7064] between Mollin Wood and Gillalees Scroggs where it is 4 ft thick and yields productids and smooth spiriferids.

East of the Shopford Fault. The tract forming the south-eastern flanks of The Beacon is drained by the headwaters of the Cam Beck and Green's Burn. Individual limestones and sandstones form a series of sub-parallel features with a north-north-easterly strike, but exposures are scattered. The Upper *Antiquatonia* Band gives rise to a broad green grassy belt near Robin Hood's Well and is exposed [5747 7116] in a small runnel. The Maidenway Limestone crops out as a strike-section in a small streamlet which rises west of The Butt; where best exposed [5791 7164], shales with bivalves overlie 2 ft or more of limestone. The latter contains an 8-in band with small algal nodules in which the internal structure is clearly visible. About 50 yd to the east is a narrow green belt with many sink-holes: it marks the crop of the Butt Limestone which takes its name from the nearby Roman signal station. The lowest 1 ft of the limestone is exposed some distance to the south [5802 7116] where it comprises 1 ft of shelly flaggy limestone overlying 2 ft of calcareous shales with crinoid debris, bryozoa, smooth spiriferids and *A. teres*.

The Whiterigg *Serpula* Band forms another belt of sink-holes south-west of White Rigg and can be traced south-westwards towards the Shopford Fault; it is exposed in a ditch [5807 7060] where it is algal and forms a typical serpulid reef with abundant ostracods. The higher Quarry Sandstone has been worked at outcrop in Whiterigg Plantation.

In other parts of the district the beds overlying the Quarry Sandstone contain algal bands and include the *Syringothyris* Limestone, but although a number of thin limestones are present in the tributary of Green's Burn, which rises in Gillalees Beacon Plantation, neither algae nor *Serpula sp.* have been recognized. At the top of the sequence are Garwood's (1931) 'Spadeadam Beds' which comprise 60 ft of fossiliferous shales including the Whitberry Band about 35 ft above the base. The shales below the band can be seen in Green's Burn [5825 7029] immediately north of the Shopford Fault, where they include a bed said by Garwood (op. cit., p. 116) to include "*Aulopora sp.*, *Michelinia grandis* M'Coy, *Palaeosmilia θ* Vaughan, *Derbyia ambigua*, *Dictyoclostus teres*, *Productus elegans*, *P.* cf. *furcatus*, *Pustula pyxidiformis* and *P. punctata*". Garwood considered this fauna to be "an impoverished representative of the Arnside *Michelinia* Zone" pointing "definitely to an horizon high in C_2 of the Westmorland succession".

Green's Burn south-west of the Shopford Fault. An algal limestone 5 ft thick, with pellet beds near base and top, crops out [5654 6996] 60 yd S.E. of the confluence of the stream with the Cam Beck. This bed overlies sandstone just below the confluence and underlies the *Syringothyris* Limestone, which crops out for 40 yd along the strike in the left bank [5659 6989] and gives the following section:

	ft
Siltstone; becoming darker and fossiliferous towards base ..	6
Limestone; abundant *Syringothyris sp.* and *Schuchertella sp.*	¼
Siltstone, grey	3½
Limestone; abundant *Syringothyris sp.* and *Schuchertella sp.*	½
Shale, banded calcareous ..	2¼
Limestone, hard; crowded with *Syringothyris sp.* and *Schuchertella sp.*	⅔
Shale, calcareous, with limestones; some bedding planes crowded with *Schuchertella sp.* ..	3 to 4
Limestone; crinoidal	1¼
Shale, sandy	2
Sandstone, flaggy	1

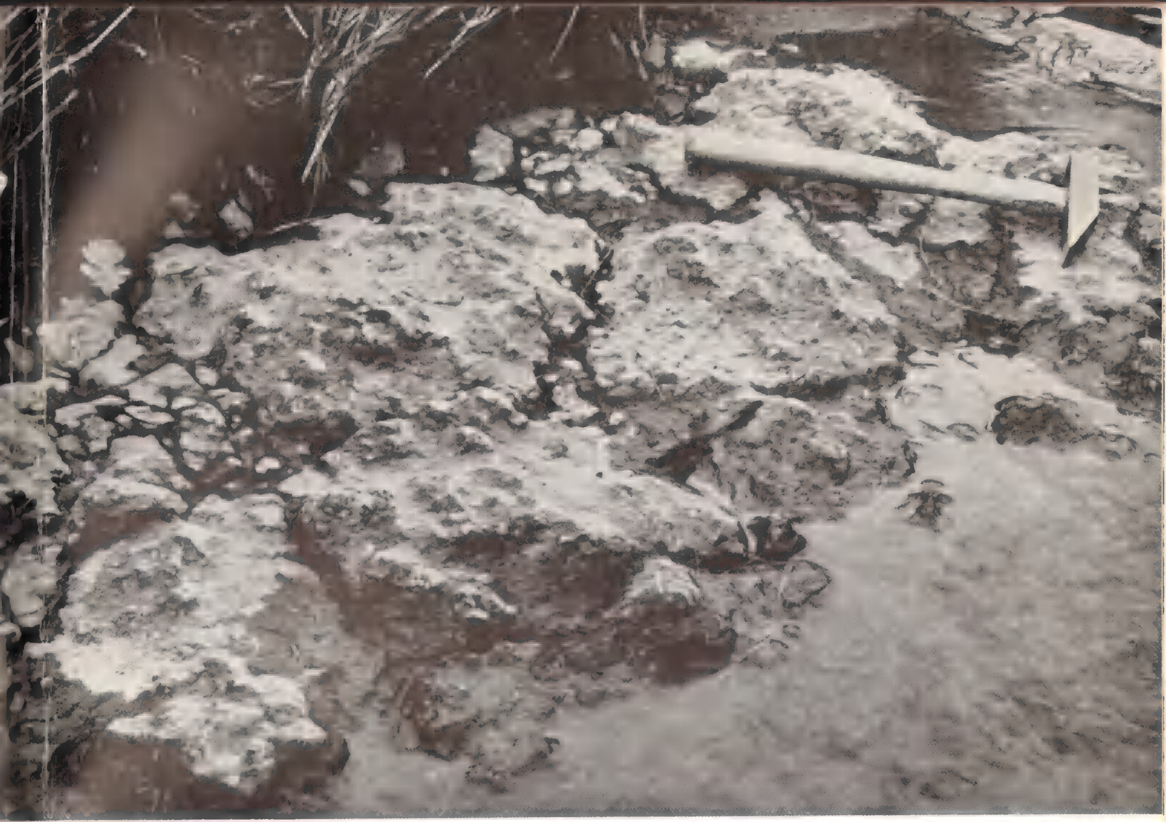
This section is terminated by a small fault, and a sandstone exposed in the left bank upstream [5676 6988] appears to lie at a higher level than the *Syringothyris* Band. This sandstone is separated by another fault from a higher shaly algal limestone [5689 6986] which is at least 2 ft thick and which is crowded with small algal pellets, reputed by Garwood (1931, p. 117) to be associated with *Spirorbis caperata*. Upstream and at a still higher horizon, are several thin limestones, one of which is 4 ft thick and has distinctive white ribs [5773 7001]. Another, 180 yd upstream, but a few feet lower in the sequence, is 2 ft thick and yields ostracods and bryozoa. The lower part of the succeeding thick shales ('Spadeadam Beds') is well exposed [5805 7012] as follows:

	ft
Shale, grey	12
Mudstone, calcareous dark ..	1⅓
Mudstone, green sandy; veined with dark material from the overlying bed	3
Sandstone, white fine-grained ripple-marked	7

About 60 yd farther upstream 20 ft of calcareous shales with thin limestone ribs are overlain by the Whitberry Band [5818 7022].

Just within the Cam Beck catchment, but north-west of the Caudbeck Fault, is the site [5910 7192] of the 400-ft Spadeadam No. 2 (Priorlancy) Bore (loc. 41) drilled in 1957. The log is given in Appendix II, p. 331.

Cam Beck between the Shopford Fault and Green's Burn. The lowest bed seen in the upper reaches of Cam Beck is a shelly limestone, 7 to 8 ft thick [5720 7059]. It lies near the base of the Upper *Antiquatonia* Band, which is represented by 30 to 35 ft of calcareous shale with thin limestone ribs, well exposed in a left-bank cliff [5725 7059]. The limestone ribs are commonly crowded with *A. teres* and other fossils, including *Syringothyris exoleta*. The shales are overlain by at least 20 ft of massive sandstone, which forms a ridge on the north-west bank, and which is succeeded in turn by 3½ ft of sandy, yellow-weathering dolomitic limestone exposed [5690 7037] along the strike for about 250 yd. Above the limestone are shale and ripple-marked sandstone [5685 7034]. An easterly strike-fault (not shown on the one-inch map) may intervene between these and sandstones [5676 7019; 5668 7012] with an intercalated 1-ft limestone [5670 7016]. Still farther downstream [5665 7008] an algal limestone is exposed in the form of a 'nobbly' pavement (Plate IIIA) at the base of about 6 ft of rather shaly limestone. The algal bed is about 1 ft thick, and '*Collenia*'-type growth-forms can be seen in the right bank a few yards upstream. The locality has yielded *Girvanella ducii*, *Ortonella furcata* and *O. tenuissima*. The horizon is tentatively equated with the Whiterigg *Serpula* Band, although *Serpula* has not been found here. The crop of the limestone is terminated to the west by a west-north-westerly fault, throwing down to the south and cutting out the immediately overlying beds. If the correlation suggested above is correct, the missing beds would include the correlatives of the thick limestone which overlies the *Serpula* Band in the Priorlancy Bore. On the downthrow side of the fault are 4 ft of shattered



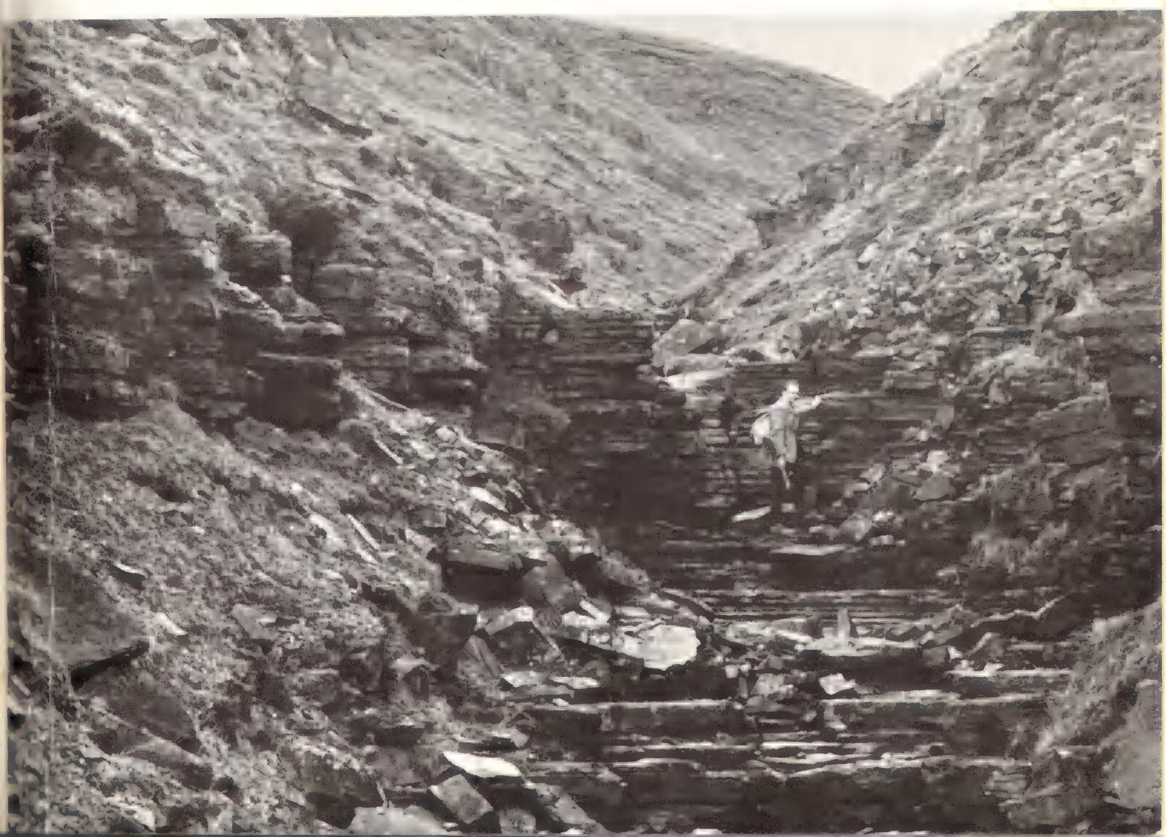
(L 446)

A. Algal limestone with typical 'nobbly' top; Cambeck Beds, Cam Beck

PLATE III

B. Birky Cleugh Limestone and overlying strata; Main Algal Beds, Birky Cleugh

(L 457)



doubtfully algal limestone exposed [5661 7006] in the left bank, and farther downstream are thin limestones with intercalated shales [5655 7002].

Cam Beck west of Green's Burn confluence. Exposures in Cam Beck between the mouth of Green's Burn and Parkgate Bridge are discontinuous and, in places, faulted.

The first of note below the confluence comprises two 1-ft beds of grey fossiliferous limestone separated by 1¾ ft of shale [5633 7008]. The uppermost limestone has yielded productids and bryozoa.

About 200 yd downstream is a further limestone, 4 to 8 ft thick [5613 7011] and containing thin algal pellet-beds, with rare *Antiquatonia teres* at top. This is the same bed as the limestone exposed along the strike in Green's Burn, 60 yd S.E. of the confluence (p. 78).

The next exposed limestone [5605 7040], nearly 100 yd downstream, is 9½ ft thick, being hard and massive in the lowest 2½ ft, but shaly and shelly above. It is underlain by 3½ ft of sandstone and sandy shale. The limestone is repeated by a north-westerly fault [5595 7051] farther downstream. On the upthrow side of the fault are 4 to 5 ft of grey limestone, with rare brachiopods and crinoid debris.

West of Parkgate Bridge two continuous sections of Cambeck Beds can be made out in Cam Beck and its north-bank tributary Melefarm Beck. The first section extends from below the Maidenway Limestone to above the Hillend Algal Band. The lowest beds are exposed in Cam Beck 40 yd W. of the bridge, but their correlation is doubtful as they are separated from the rest of the section by a northerly fault [5547 7041]. The Maidenway Limestone, 7 ft thick, crops out [5544 7042] west of the fault and the Butt Limestone, a few yards downstream, consists of 14 ft of alternating limestone and shale. The lower of the two *Syringothyris*-bearing beds of Muckle Hare Grain (p. 76) is represented in Melefarm Beck [5543 7048] by a thin rib of limestone crowded with *Syringothyris sp.* and *Schuchertella sp.* and associated with about 20 ft of calcareous shales. The Quarry Sandstone crops out around the mouth of Melefarm Beck and is overlain by 3 ft of nodular algal limestone. The *Syringothyris* Limestone [5527 7043] consists of thin limestone bands crowded with *Syringothyris sp.* and *Schuchertella sp.*, and overlies nearly 30 ft of fossiliferous calcareous shales. There follows an unexposed interval coinciding with the estimated position of the Hillend Algal Band. Above it are partially reddened sandstones and shales [5524 7044]. About 10 ft of sandstone in the right bank [5515 7046] represents the highest horizon of the section, but a north-westerly fault, throwing down about 75 ft to the north, repeats lower measures including the *Syringothyris* Limestone in the left bank [5512 7037]. The limestone is overlain in the opposite bank, near the fault, by the Hillend Algal Band consisting of two thin nodular algal limestones which enclose a thicker, non-algal, dolomitized limestone. About 300 yd downstream and beyond another north-westerly fault are 6 to 8 in of algal limestone, containing macroscopically distinct algal tubules. This bed, together with the overlying 6 ft of massive sandstone, is gently folded, and probably lies fairly high in the succession.

The second continuous section (Appendix I, p. 277 and Fig. 17, No. 4) occurs between the Askerton and Low Park faults; it consists of reddened strata extending from the Upper *Antiquatonia* Band to just below the Hillend Algal Band. A notable fauna obtained from calcareous shales [5430 6955] lying just over 20 ft above the Whiterigg *Serpula* Band includes trepostome bryozoa, *Antiquatonia teres*, *Schuchertella ambigua*, *Syringothyris exoleta*, *Aviculopecten plicatus*, *Fenestella sp.*, *Sanguinolites* cf. *tricostatus and Punctospirifer scabricosta* North. This is the lowest horizon at which *P. scabricosta* has been found, and is one of the few known occurrences of the species within the Lower Border Group (p. 73).

The section is terminated by the Low Park Fault which throws down Middle Border Group rocks to the west against the Hillend Band to the east. The band is seen at two localities [5415 6954 and 5414 6938] to consist of 4 ft of pink, nodular algal limestone overlain by large reef-like algal masses which are encrusted with *Spirorbis sp.* and bryozoa and set in shale. At the northernmost exposure the beds are disturbed and folded close to the fault, which can be seen in the stream bed [5411 6937].

King Water. Scattered exposures referable to the Cambeck Beds occur near the head of the King Water, west of Hen Hill. They include several limestones [5979 7346; 5986 7345; 6001 7343], but there is no continuous section. A north-westerly fault, throwing down to north-east cuts the stream at two places [7342 6003; 7335 6007]; on the south side of the valley [6002 7340; loc. 43], on the upthrow side of the fault, is a bed of sandstone which includes a calcareous band, algal at the top. This band has yielded *Garwoodia gregaria*, *Girvanella amplifurcata*, *G. ducii* and *Ortonella furcata*; it appears to lie low in the Cambeck succession. Other sandstones are exposed in the stream south of Hen Hill.

LOWER AND UPPER IRTHING CATCHMENTS

Cambeck Beds are exposed discontinuously within the headwaters of the Butter Burn. In Rob's Sike, north of an east–west fault [6030 7473], about 3 ft of shaly limestone with *Antiquatonia teres* floors the stream for more than 100 yd, while south of the fault the stream runs on sandstone at a slightly higher horizon.

In the Butter Burn 1 to 2 ft of limestone crop out [6085 7424; loc. 44] north-east of Jock's Hill. It is succeeded at a higher level by a thin nodular algal limestone which has yielded *Aphralysia sp.* and *Girvanella wetheredii* as well as *Pustula sp.* and *Schuchertella ambigua*. About 40 yd downstream the Whitberry Band crops out (loc. 56a) at the mouth of a small northern tributary where 7 to 8 ft of calcareous shales, with limestone ribs, have yielded *Rugosochonetes cumbriensis*, *Ovatia bioni*, *Aviculopecten sp.* and ostracods.

Sandstones overlying the Upper *Antiquatonia* Band crop out near the head of Hazel Gill and in Redpath Sike on Highgrains Waste. At Black Murches Crags, 8 to 12 ft of Barron's Pike Sandstone emerge from the peat. Near the head of Foulbog Sike, just south of the Antonstown Fault, outcrops include a calcite-veined crinoidal limestone with ostracods [6074 7744]. About 400 yd downstream another veined limestone, 2 to 3 ft thick, with included shale fragments, has yielded sparse *A. teres*. J.B.W.D.

LEWIS BURN CATCHMENT

North of the Lewis Burn–Troughend Dyke there are scattered exposures of greenish and fine-grained sandstone, assigned to the Cambeck Beds. A petrographic description is given on p. 213.

In a stream [579 850], about 200 yd S.E. of Hell's Bottom, the following section was measured:

	ft
Sandstone, thinly-bedded fine-grained siliceous; iron oxide specks	6
Not exposed	about 4
Mudstone, grey calcareous; some 2-in limestones; ostracods ..	4
Limestone, grey weathered buff; ostracods (forms stream bed for 50 yd)	1
Not exposed (shale debris) ..	2
Limestone, grey weathered buff; ostracods	1

Another limestone, similar to the basal member of this sequence, is exposed 50 yd downstream.

In a sike, 15 yd S. of the Lewis Burn–Troughend Dyke, 2 ft of grey decalcified mudstone are exposed [5841 8549]. In another sike [5824 8513] ¼ mile to S.S.W. stratigraphically higher beds are represented by 6 ft of grey shale, with several thin crinoidal limestone partings. Farther south-west, the outcrops of two thin limestones can be traced by lines of sink-holes. There are also scattered small exposures of calcareous shales with thin limestone partings and calcareous sandstones. D.H.L.

REFERENCES

ANDERSON, F. W. 1950. Some reef-building calcareous algae from the Carboniferous rocks of northern England and southern Scotland. *Proc. Yorks. geol. Soc.*, **28**, 5–28.

CARRUTHERS, R. G., BURNETT, G. A. and ANDERSON, W. 1930. The geology of the Alnwick district. *Mem. geol. Surv. Gt Br.*

FOWLER, A. 1936. The geology of the country around Rothbury, Amble and Ashington. *Mem. geol. Surv. Gt Br.*

GARWOOD, E. J. 1913. The Lower Carboniferous succession in the north-west of England. *Q. Jl geol. Soc. Lond.*, **68**, 449–586.

—— 1931. The Tuedian Beds of northern Cumberland and Roxburghshire, east of the Liddel Water. *Q. Jl geol. Soc. Lond.*, **87**, 97–159.

GEORGE, T. N. 1958. Lower Carboniferous palaeogeography of the British Isles. *Proc. Yorks. geol. Soc.*, **31**, 227–318.

LUMSDEN, G. I., TULLOCH, W., HOWELLS, M. F. and DAVIES, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

MCKEE, E. D., REYNOLDS, M. A. and BAKER, C. H. 1962. Laboratory studies on deformation in unconsolidated sediment. *U.S. geol. Surv. Prof. Paper*, 450-D, D151-D155.

NAIRN, A. E. M. 1956. The Lower Carboniferous rocks between the River Esk and Annan, Dumfriesshire. *Trans. geol. Soc. Glasg.*, **22**, 80–93.

NICHOLSON, H. A. 1888. On certain anomalous organisms which are concerned in the formation of some of the Palaeozoic Limestones. *Geol. Mag.*, **5** (I), 15–24.

VAUGHAN, A. 1905. The palaeontological sequence in the Carboniferous Limestone of the Bristol area. *Q. Jl geol. Soc. Lond.*, **61**, 181–307.

Chapter IV

MIDDLE BORDER GROUP

General Account

The Middle Border Group is defined as extending upwards from the base of the Whitberry Band (*Chonetes cumbriensis* Band of Garwood 1931) to the base of the Clattering Band. Its thickness varies from approximately 1000 ft in the River White Lyne to 1500 ft in the northern and north-eastern parts of the district; around Spadeadam in the south-east it is about 1300 ft thick.

Within the district, the group is represented by two distinct facies. In most places it is very little different from the underlying group, consisting of rhythmic sequences of limestone, shale and sandstone, with subordinate seatearths and thin coals (Fig. 18). In the north-eastern part of the district, however, only the upper third of the group conforms to this description; the lowest two-thirds consist mainly of sandstones with subordinate unfossiliferous mudstones. Moreover, since neither Whitberry nor Clattering bands have been recognized in the north-east, the boundaries of the group are there ill defined.

The limestones, some of which are algal, are mainly thin and impersistent. In the River White Lyne shales, having a varying content of sand, account for approximately half the thickness of the group, but this proportion dwindles to to the north and north-east. Seatearths occur at several horizons but they are associated with coals only in the upper part of the group. The coals, which are too thin to be of economic value, are virtually the first to have been formed in the district though seatearths were being formed as early as Lower Border Group times.

The sandstones within the rhythmic sequences are locally thick. In the lower part of the group, for instance, a 90-ft arenaceous sequence has been proved in a borehole at Spadeadam, and sandstone 250 ft thick underlies a basalt at about the same horizon at Kershopefoot; the Oakshaw Sandstone near the top of the group attains a maximum thickness of 140 ft in the River Black Lyne north of Dodgsontown. The sandstones are generally compact, well cemented, moderately graded, usually fine- or medium-grained and not notably micaceous except for the shaly bands: in northern and eastern parts of the district, chlorite commonly imparts a greenish tint. Many of the sandstones are current-bedded and the predominant direction of dip in the foreset beds is towards the south-west. Irregularly contorted beds (as defined by McKee and others 1962, p. 152) were seen at several levels. The contortions are probably attributable to horizontal load flowage from the weight of sediment accumulating on the margin of a current-fed deposit (Prentice 1960, p. 220). The mudstones associated with sandstones in the north-eastern part of the district are generally greenish grey or purple and are unfossiliferous; many of them are silty.

Volcanic rocks of Middle Border Group age are represented at outcrop only

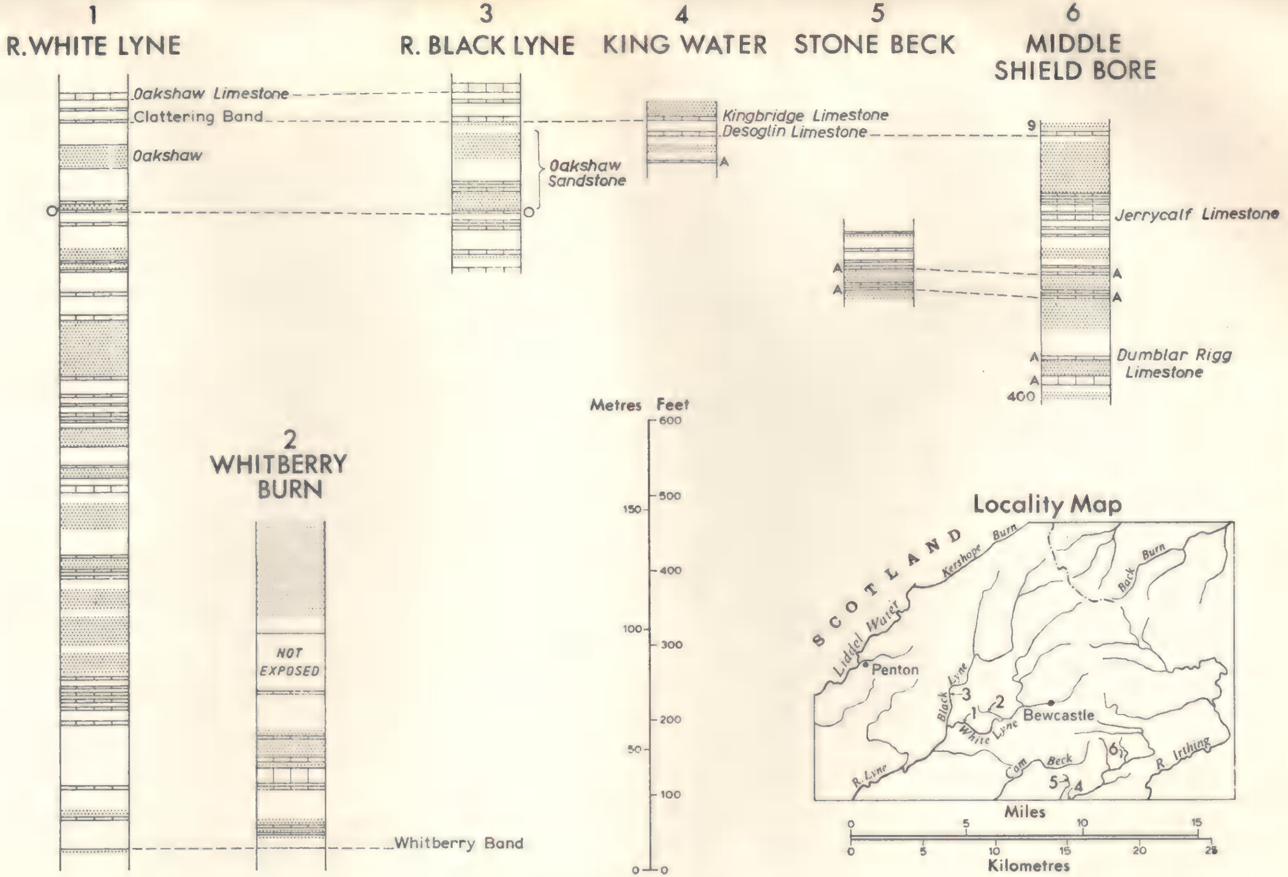


FIG. 18. *Comparative vertical sections of the Middle Border Group and immediately overlying strata. For key see Fig. 5*

by the olivine-basalt lava of Kershopefoot, but tuffs forming the lower part of the Glencartholm Volcanic Beds occur below the position of the Clattering Band in the Archerbeck Bore (Lumsden and Wilson 1961, p. 12) and probably continue at depth across the Scottish border into the western part of the district.

In the south-eastern part of the district, limestones and shales at the top of the Middle Border Group were loosely termed Kingwater Beds by Garwood (1931) who obtained from them a fauna which he compared with the S_1 fauna overlying the Ashfell Sandstone in Ravenstonedale. Trotter (*in* Trotter and Hollingworth 1932, pp. 29-32) defined these beds more precisely as consisting of 100 ft of strata including four limestones (the Kingwater Limestones) named in ascending order the Cementstone, Productus, Lamellibranch and Martini limestones. From re-examination of the long strike sections exposed in the King Water, however, it is now apparent that the Lamellibranch and Productus limestones are merely lateral variations of a single bed which is here renamed the Desoglin Limestone. Moreover, the Cementstone Limestone, which Trotter used to define the base of the Bernician, lies so close to the base of the overlying Desoglin Limestone as to be regarded as part of it. The Kingwater Beds are thus redefined as consisting of two thin limestones, the Desoglin Limestone below and the Kingbridge (formerly Martini) Limestone above, separated in the type section by 16 ft of mainly shaly strata.

The remains of plants occur at several horizons within the group, but the most spectacular examples of fossil vegetation were seen in a bed of argillaceous flaggy sandstone about 40 ft below the top of the group where a number of stumps of *Pitys primaeva* (Witham), still in positions of growth, were observed at two localities in the King Water. At the more north-easterly locality, in the river bed on both sides of the mouth of Trout Beck (Fig. 21), ten stumps, the largest of which measures more than 8 ft across the bole, were seen within a linear distance of 200 yards. A single stump is present at the other locality two miles downstream.

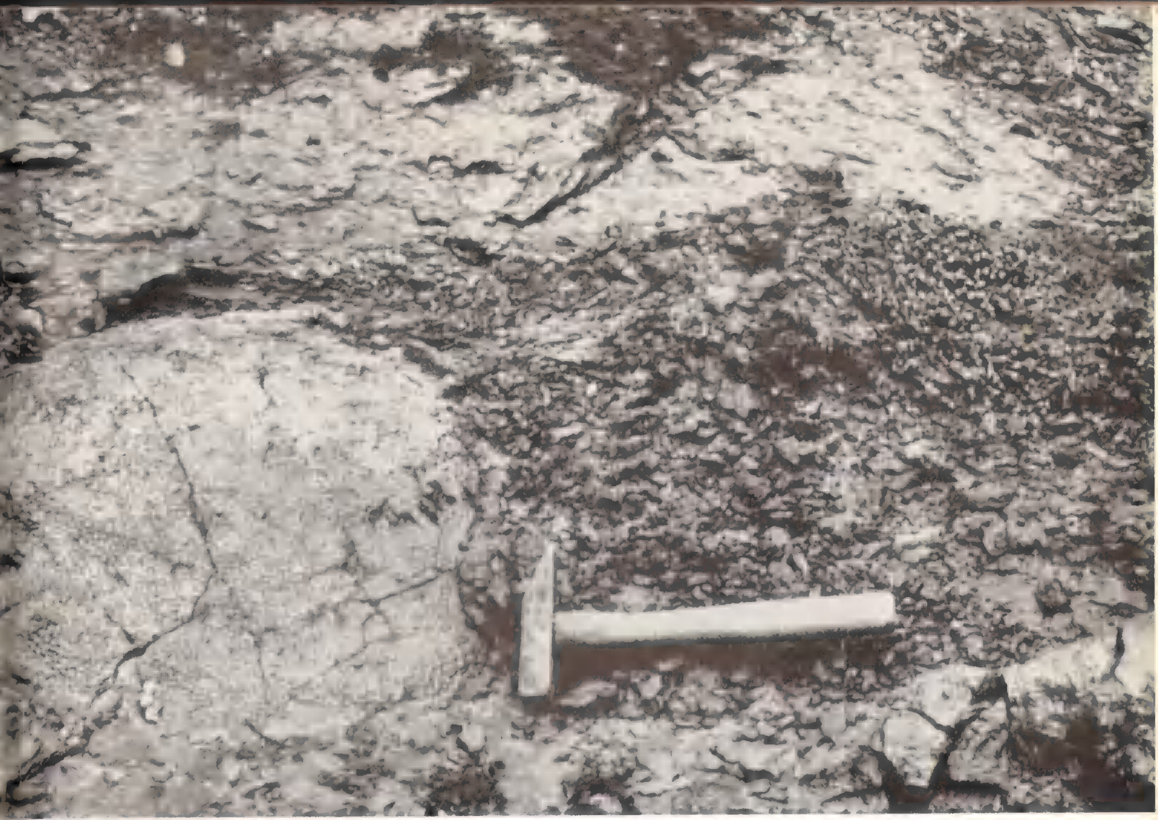
DETAILS

KERSHOPE BURN CATCHMENT

Riding Grain. Sparsely fossiliferous strata are exposed in Riding Grain and its tributaries upstream from the westernmost branch of the Wythes Fault and are assigned on lithological grounds to the lower part of the Middle Border Group. They are much disturbed by the Wythes Fault and by associated fractures and folds. The oldest beds are exposed between two faults [5566 8705 and 5573 8704], one of which [5566 8705] is the westernmost branch of the Wythes Fault (Fig. 19, I) and are from east to west:

	ft
Sandstone, some gaps	20
Poorly exposed, some mudstone	5
Sandstone	8
Not exposed	6
Sandstone	6
Mudstone, rooty	2
Sandstone, rooty	4
Mudstone, sandy, rooty ..	1
Not exposed, some sandstone ..	4½
Sandstone, brown massive ..	10
Sandstone; carbonaceous markings and rare brachiopods ..	1
Not exposed	5

Beds somewhat higher in the sequence appear upstream in Riding Grain and are partly repeated in the south tributary (Fig. 19, II; loc. 45a). The section measured downstream from a fault [5582 8705] is:



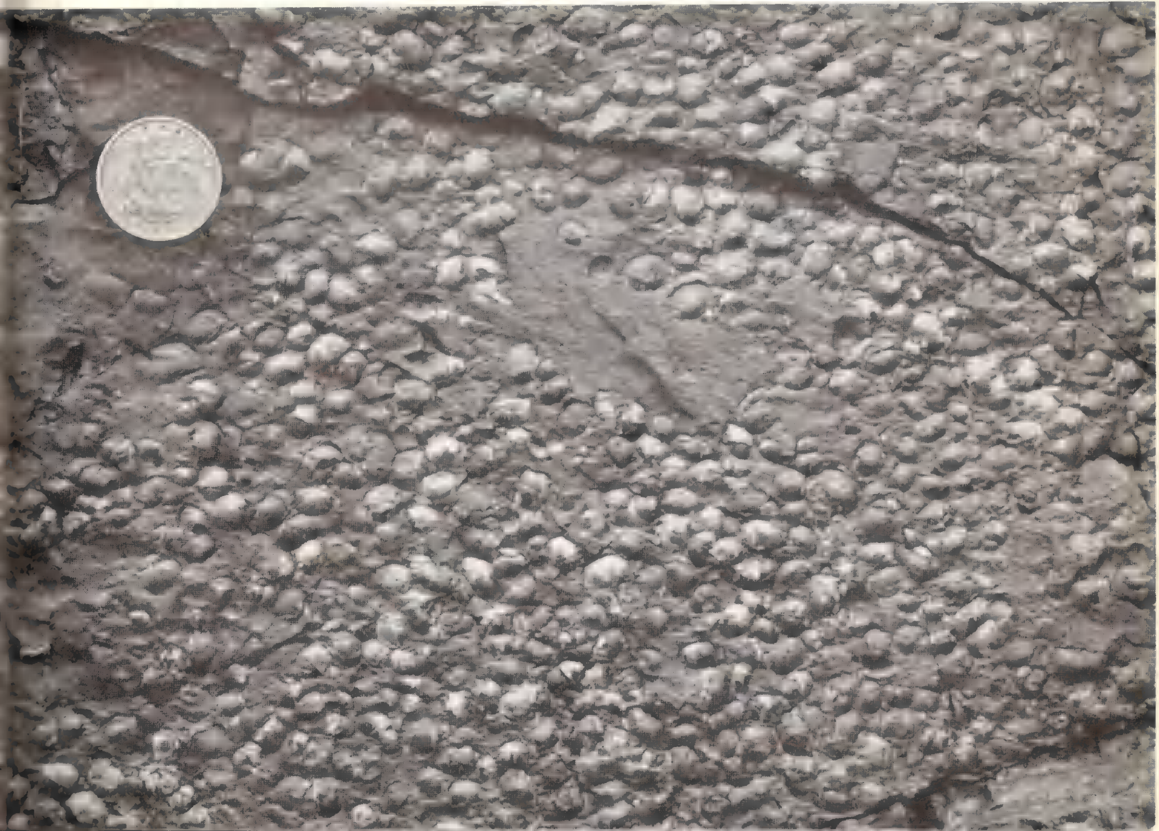
(L 472)

A. CLATTERING BAND, WITH *LITHOSTROTION* COLONIES IN POSITIONS OF GROWTH; RIVER BLACK LYNE

PLATE IV

B. WHITBERRY BAND, WITH ABUNDANT *RUGOSOCHONETES CUMBRIENSIS* AND OSTRACODS; WHITBERRY BURN

(L 470)



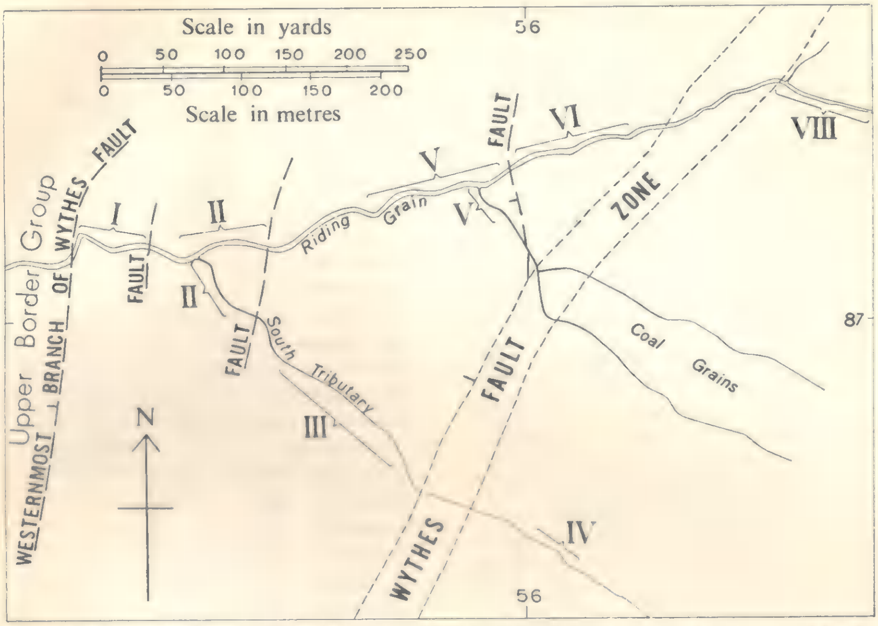


FIG. 19. *Sketch-map of Riding Grain and its tributaries, showing locations of Middle Border Group sections described in the text*

	ft	in
Mudstone, grey		1
Cementstone, hard grey		9
Mudstone, brown rooty		1
Coal		1
Limestone, brownish grey; ?*Lingula sp.*		9
Mudstone, brownish rooty		3
Coal		6
Mudstone, grey rooty		6
Rottenstone, soft sandy		9
Sandstone	1	3
Not exposed	1	3
Mudstone, rooty		3
Mudstone, silty: ?*Lingula sp.*		6
Sandstone, fine-grained grey	4	0
Mudstone, sandy rooty	5	6
Shale, dark fossiliferous	1	0
Coal, impersistent		3
Mudstone, rooty at top	3	9
Cementstone, barren grey		9
Mudstone, grey-green	1	3
Shale, calcareous	1	0
Limestone; shale band; *Serpula sp.*	2	9
Sandstone, rooty at top	15	0
Mudstone; ironstone nodules	1	8
Limestone, grey		6
Shale, carbonaceous		3

	ft	in
Mudstone, rooty		8
Not exposed	2	0
Mudstone, rooty at top, calcareous; fossiliferous towards base	6	0
Mudstone, grey silty	3	0
Sandstone; plant fragments	7	0
Mudstone, grey sandy		6
Mudstone, grey limy; bivalves at top, indeterminate shell debris near base	7	0
Shale and mudstone	2	0
Not exposed	2	0
Mudstone, rooty at top, calcareous at base	4	6
Not exposed	2	6
Limestone; poorly preserved bivalves	2	0
Sandstone	5	0
Fault		

The top 40 ft of this section are repeated at the base of the following sequence measured higher up the South Tributary (Fig. 19, III; loc. 45b):

	ft	in
Sandstone, thin shaly bands [5588 8690]	24	0
Mudstone, grey, small nodular structures: ?tuffaceous	5	0

	ft	in
Siltstone, greenish nodular: ?tuffaceous	3	6
Mudstone, sandy, nodular structures, thin sandstone bands	11	0
Siltstone, greenish; ?tuffaceous		6
Sandstone, shaly towards base	5	6
Mudstone, shaly	1	0
Cementstone, brownish		6
Mudstone, rooty		4
Coal		3
Limestone, brownish grey	1	0
Mudstone, brown rooty		6
Coal and carbonaceous shale		6
Mudstone	3	0
Sandstone, fine-grained	3	6
Mudstone, grey	6	0
Coal and carbonaceous shale		8
Fireclay-mudstone, shaly	1	9
Mudstone, grey sandy; calcareous towards base	6	9
Limestone, sandy	2	3
Sandstone, rooty at top	6	0
Not exposed	4	0
Sandstone	5	0

Still higher measures are exposed farther up the South Tributary, above the main Wythes Fault Zone (Fig. 19, IV; loc. 45c):

	ft
Mudstone, grey shaly; rare shells and fenestellids	1
Mudstone, calcareous, thin bands of detrital limestone	1
Mudstone, grey	½
Sandstone	8

A succession measured in the middle reaches of Riding Grain and the lower waters of Coal Grains (Fig. 19, V; loc. 45d) can probably be correlated with the whole of Section I and the basal part of Section II above. It is as follows:

	ft
Sandstone	3
Mudstone, sandy	1
Not exposed; mudstone debris	5½
Sandstone, thinly bedded	11
Mudstone, silty; ostracods	¾
Limestone, brownish-grey	1
Mudstone, carbonaceous	½
Mudstone, rooty	¼
Not exposed; sandstone debris	7
Limestone, shelly at base	2¼
Sandstone	3¼
Not exposed	1
Limestone, ? *in situ*	2
Not exposed	1½
Sandstone, fine-grained	3
Cementstone, passing laterally into grey sandy mudstone	½
Sandstone, fine-grained massive	3
Mudstone, grey sandy	3
Sandstone	5
Not exposed	5
Sandstone	7½
Mudstone	1
Sandstone with some gaps	5
Not exposed	about 25
Sandstone, fine-grained	3
Not exposed	about 9
Mudstone, plant remains	1
Not exposed	2
Mudstone, rooty	¼
Mudstone, silty	¾
Sandstone; band of calcareous nodules containing rootlets	16
Not exposed: possible fault	about 15
Sandstone, shaly at base	4
Mudstone, coaly band rooty at base	10¼
Sandstone	9
Limestone: possibly algal	1
Sandstone, thin-bedded	2
Mudstone, grey: microfossils	1
Not exposed	4
Sandstone	1
Not exposed	5
Sandstone	3

Farther up Riding Grain as far as the main Wythes Fault Zone (Fig. 19, VI; loc. 45e) the section is:

	ft
Sandstone; two thin mudstone bands	20
Mudstone, sandy at top, rooty at base	11½
Sandstone; bivalves at base	9
Mudstone	6
Sandstone, fine-grained grey-green	8
Mudstone, sandy and rooty	6
Sandstone; shelly casts	6
Sandstone, soft decalcified	½
Sandstone, thin-bedded ripple-marked	2
Not exposed	2
Sandstone, thin-bedded	2¾
Not exposed	¼
Sandstone, grey calcareous, apparently passing laterally into sandy limestone	2
Mudstone, rooty	½

The correlation of Section VI is uncertain: it may be equivalent to the middle part of Section V and thus to Section I also. Alternatively it may lie much higher in the succession, between sections III and IV.

The section occupying the highest stratigraphical position in Riding Grain lies above the main Wythes Fault (Fig. 19, VIII). The higher beds are about equivalent to Section IV above and the lower beds may represent Section VI.

	ft
Mudstone, grey shaly, calcareous at base; shell debris	4
Not exposed; probably sandstone	10
Sandstone, waterfall	6
Not exposed	15
Sandstone, poorly exposed	25
Massive sandstone	3
Not exposed	7
Sandstone, grey-green silty ?tuffaceous	1
Not exposed	4
Siltstone, greenish ?tuffaceous	2
Mudstone, sandy, rooty in parts	5
Sandstone, greenish rooty	1½
Sandstone	9
Not exposed; some coal debris	3
Sandstone, some gaps, rooty at top	11
Sandstone and mudstone in alternation	5½
Mudstone, rooty; calcareous band	4
Sandstone, mudstone band	10
Mudstone, silty, coaly and rooty towards base	2½
Not exposed	1½
Sandstone	½
Not exposed	8½
Sandstone	5½

The following section, measured in the sides of the spur between the two branches of Coal Grains, probably represents the lowest 60 ft of Section II:

	ft
Mudstone, mostly rooty, some sandstone and two coaly bands; contorted beds	27½
Sandstone, thin-bedded	6
Mudstone, sandy	1
Mudstone, brownish, decalcified at top; fossiliferous	3
Mudstone, grey; carbonaceous band at base	4
Mudstone, grey rooty	2¼
Mudstone, brownish sandy	2½
Mudstone, calcareous; shelly band	7
Sandstone, brown-weathering, calcareous	½
Limestone, grey sandy; poorly preserved bivalves	1¾
Not exposed	2
Sandstone	2

Middle Border Group strata are also exposed discontinuously in the upper reaches of Upper and Nether Castle cleughs: a 6-inch coal resting on seatclay and overlain by shale crops out in the former [5581 8650], and 30 yd upstream from the coal is a 3-ft brown-weathering sandy limestone with ostracods.

Sandstones higher in the sequence form distinct features round the western slopes of Glendhu Hill and include the prominent Dove Crags [5606 8631] rock which is brownish, medium-grained, massive and current-bedded and is upwards of 30 ft thick. Other smaller crags emerge through the peat towards the northerly branch of the Harrett's Linn Fault, which locally forms the southern limit of the Middle Border Group outcrop.

Kershope Burn. In a narrow strip of country between the Kershope Fault and the Liddel Water, north-east of Craggy Cleugh, rocks of Middle Border Group age underlie the Kershopefoot Basalt (p. 242). The northernmost section in the river [5475 8662] is adjacent to the fault and consists of:

	ft
Marls, red and grey mottled; cherty nodules	4
Sandstone, medium-grained	2
Marls, red and green	2½
Sandstone, biscuit-coloured medium-grained, finely current-bedded	4

Downstream from this locality are several outcrops of sandstone with a few thin limestones and shales. Still farther downstream [5379 8627] are several feet of white, current-bedded sandstone with slickensided bedding planes: it is a medium-grained rock becoming coarser towards the base, with quartz pebbles up to 1-inch diameter. It is the highest bed exposed below the Kershopefoot Basalt [5370 8626]. Beds immediately overlying the basalt are not exposed here, but higher measures crop out in Craggy Cleugh [5313 8557], a few yards east of a northerly branch of the Kershope Fault which brings on Upper Border Group rocks to the west. The section is:

	ft
Shale, grey-blue calcareous; microfossils	1
Mudstone, grey rooty	2¾
Limestone, dark grey earthy; carbonaceous markings .. about	1
Not exposed	1½
Limestone, fine-grained grey crystalline	2¼
Not exposed	3½
Sandstone, grey-brown rubbly rooty	1¼
Seatclay, grey	1¼
Limestone, grey earthy	1½
Limestone, fine-grained grey crystalline; ostracods and rare brachiopods (beds vertical striking N. 57° E.)	1½
Not exposed	7
Shale, grey	¼
Limestone, nodular grey	⅓
Shale, grey	⅓
Limestone, grey earthy nodular; *Myalina sp.*	½
Mudstone, grey-green, rootlets	3½
Shale, grey limy, nodules of grey earthy limestone rich in *Myalina sp.*	6

About 500 ft of Middle Border Group rocks also crop out in a syncline, bounded by faults to south-west and north-east, between Kershopefoot and Golden Cleugh. The lowest bed is sandstone, 250 ft thick, its base cut out at the western end of the syncline by a branch of the Kershopefoot Fault [4791 8289]. At several old quarries in the hillside south of the road leading eastwards from Kershopefoot village, the sandstone is massive, medium-grained and locally slightly calcareous. At the eastern end of the syncline the bed is mainly obscured by drift, but micaceous and flaggy sandstone is exposed in the burn below the road-bridge [5012 8345] and at several places on the steep valley side north-east of Kershope Bridge. Pale grey, fine- to medium-grained and rooty sandstone is also exposed in the left bank of the burn [5070 8401], 265 yd S.W. of the mouth of Golden Cleugh.

The sandstone is overlain by the Kershopefoot Basalt (p. 242), which is about 120 ft thick. It has an arcuate outcrop open to the south, so that the two ends cross the burn to lie in England, while the centre forms Carby Hill in Scotland. The basalt is probably a lava contemporaneous with, or a little older than, the lowest of the Glencartholm Volcanic Beds of the Esk, farther west (Peach and Horne 1903, p. 846; Nairn 1956, p. 85). Neither bottom nor top contact of the basalt is exposed, but beds within about two feet of the upper junction can be seen in several places. The following section of beds overlying the basalt was measured on both banks of the Kershope Burn [4921 8300 to 4930 8302]:

	ft	in
Sandstone, conglomeratic, with shell debris and calcite crystals	1	6
Limestone, cherty and yellow-weathering	2	0
Seatclay, grey	1	0+
Not exposed		?
Limestone, fawn cherty with root-like markings and a surface showing a reticulate network of veins	1	0
Shale		3
Limestone, cherty; black root-like markings	1	3
Shale		3
Limestone, blue-grey with bands (?bedded) of black chert	1	6
Coal		1
Limestone, hard with large inclusions of black chert; upper surface irregular with a pseudo-brecciated appearance; well-jointed with quartz veins along dip-joints; pyrite segregations common	1	6
Seatclay, greenish	1	0

About 200 yd to the north-east, in the right bank of the stream [4943 8312], 3 ft of yellow-weathering, light grey, cherty, veined limestone lies within 2 ft of the top of the basalt. Still farther to north-east [4973 8332] this limestone strikes diagonally across the stream, and is at least 5 ft thick, yellow-weathering and cherty with a pseudobrecciated appearance caused by partial recrystallization. It contains small segregations of pyrite, with some joint planes covered by greenish redistributed chlorite, and others thinly coated with bitumen. Farther downstream are disconnected exposures which include several thin, sparsely fossiliferous limestones, thin calcareous shales and rubbly rooty sandstones.

At the western end of the syncline, the limestone closely overlying the basalt can be seen dipping to the south-east in Clinty Sike [4820 8272]. In addition to features already described it includes at its base a lens of hard, grey limestone up to 2 ft thick which must lie very close to the top of the basalt.

The highest measures in this part of Kershope Burn form a strike section [4863 8280] consisting of a series of limestones and calcareous shales overlain by seatearths and shales with a thin coal. The calcareous beds contain small productids and other brachiopods as well as *Fenestella sp.* The sections given below are in stratigraphical order from the top downwards, but there may be gaps of a few feet between them:

	ft	in
Mouth of Storey's Sike [4881 8285]:		
Shale, blue-grey	1	6
Shale, grey		6
Shale, dark grey rooty; coal streaks		4
Shale, black coaly	1	0
Shale, grey rooty, small nodules and a coalified tree trunk ..	1	6
Sandstone, grey rooty		
Kershope Burn, left bank [4867 8283]:		
Sandstone, brown-weathering medium-grained current-bedded; ironstone concretions		6
Not exposed	2	6
Shale, blue-grey rotten sandy ..	1	3
Shale, hard dark grey sandy ..		6
Limestone, blue earthy white-mottled; rare fossils		1½
Coal		2
Shale, grey soft rooty; irony at base	1	0
Shale, black carbonaceous ..		1
Shale, dark grey rooty; hard bands	1	3
[4862 8280]:		
Shale, dark grey hard calcareous; small productids		3
Limestone, grey fine-grained; microfossils	1 ft 6 in to 2ft 0 in	
Shale, dark grey crinoidal ..	1	0
Limestone, blue-grey fine-grained; rare microfossils, small brachiopods and productid spines in upper part	2	0
Not exposed		?
[4885 8289]		
Shale, dark grey		½
Limestone, grey shaly fine-grained; *Fenestella sp.* and abundant small productids in bands		1¾
Shale, grey calcareous; small productids		1½
Limestone, blue-grey fine-grained; fossiliferous bands with *Chonetes sp.* and *Fenestella sp.* (not collected)		1½
Shale, grey calcareous; brachiopods at base		1¼
Limestone, blue grey, partly crystalline; bands of brachiopods; worm-like markings on surface ..		4

The lower part of this sequence may be correlated with the disconnected exposures of thin limestones and shales exposed along the strike upstream and referred to above. Two specimens in the Garwood collection—Nos. 69286–7—not identified by Garwood and vaguely located as coming from 'limestone above basalt at Kershopefoot', have been found to contain *Dyscritella nana;* they were almost certainly collected from one of these beds.

LIDDEL CATCHMENT

If the limestone formerly worked in Leagair Quarry [475 794] is the Lawston or Cumcrook Limestone (p. 114), the northerly dip should bring in Middle Border Group rocks to the south of Leagair between Liddel Tower [4773 7875] and Brownknowe [4750 7913] and extending as far south as the Parkhouse Fault. It is not so shown on the one-inch map because of the uncertainty of the correlation and because exposures are limited to isolated outcrops of sandstone.

LYNE CATCHMENT

On the one-inch map Middle Border Group strata are shown flanking the noses of plunging anticlines in the Fellend and North Greenhill areas, on each side of the Lyneholmeford fault-belt. Because of the cover of drift there are no exposures and these outcrops have been shown conjecturally on structural grounds.

BLACK LYNE CATCHMENT

River Black Lyne. Rather more than 200 ft of strata immediately underlying the Clattering Band are exposed in the Black Lyne, south of Dodgsontown Ford. The lower part of this sequence consists of cyclic deposits including four limestones and a single thin coal. The upper part consists almost entirely of the Oakshaw Sandstone, which is 100 ft thick split into two main parts by 38 ft of shales with four thin limestones. Some of the limestones are too thin to be shown individually on Fig. 18. Details of the section are given in Appendix I (p. 296).

Much of this sequence is repeated in disconnected exposures in the stretch of river north of Dodgsontown Farm. Towards the western end of this reach several thin limestones occur on both banks. At one locality on the left bank [5023 7582] 8 ft of limestone rest on 1 ft of coal and carbonaceous shale and these beds are correlated with the limestone and coal underlying the Oakshaw Sandstone. The sandstone itself can be seen a short distance upstream in a shallow gorge where it is massive, medium-grained, current-bedded, rarely calcareous and at least 140 ft thick. In the river immediately north of Oakshaw Bridge the sandstone includes thin bands of limestone, one of which [5132 7632] is 3 ft thick and partially reddened, particularly along joints. Iron-rich water seeps from the sandstone overlying the reddened limestone hereabouts.

Sleet Beck (loc. 47). Alternating shales and thin limestones occupying a position low in the Middle Border Group are exposed in Bartle's Burn (Sleet Beck) [4950 7798], 110 yd W.N.W. of Craiggy Ford Farm; they are succeeded in turn by saccharoidal, rooty sandstone and by 2½ ft of barren cementstone which crops out immediately south-west of the farm buildings. Downstream as far east as the road-bridge, sandstone, at least 100 ft thick, occupies the stream; it forms a feature which can be traced some distance to the east of Craiggy Ford, where there are old shallow quarries in the hillside. The sandstone is medium-grained, massive, poorly cemented and saccharoidal, and is very similar, lithologically, to the massive beds of the 'Fell Sandstone' of Northumberland. South of the roadbridge higher beds are seen in a series of sections separated by gaps in the succession which are probably small. For this reason the sections are laid out below in stratigraphical order:

[4961 7689 to 4963 7700]:	ft	in
Shale, rooty grey; rubbly partings; plant debris	5	6
Shale, calcareous; limestone bands	3	0
Shale, grey; calcareous nodules at base	1	0
Coal		½
Shale, coaly		3
Fireclay, grey; ironstone nodules	2	0
Shale, sandy rooty	2	6
Coal		1½
Shale, grey; abundant plant debris	1	0
Shale, grey; sandstone band at top	1	4
Shale, grey	6	0
Shale, calcareous; limestone ribs; crinoids and productids	3	0
Shale, dark grey calcareous; fossiliferous	3	0
[4964 7710]:		
Shale, grey sandy, calcareous towards base	2	0
Limestone, fine-grained, dark; ostracods and rare *Spirorbis sp.*		6
Cementstone, dark grey shaly	18	0
Coal		2
Shale, coaly		3
Shale, grey rooty	1	0
Not exposed		–
Sandstone, medium-grained current-bedded; saccharoidal in places	3	0

[4964 7741] In a tributary and separated from last section by a fault of unknown, but probably small, throw:

	ft	in
Shale, grey	1	0
Sandstone, grey shaly flaggy	1	0
Not exposed	4	0
Shale, grey calcareous	2	0
Limestone, grey, impure; crinoidal	4	0
Shale, grey calcareous; crinoid and productid debris	5	6
[4965 7739]:		
Sandstone, light grey medium-grained massive	5	0

	ft	in
Shale, sandy	2	0
Coal and coaly shale		3
Fireclay, grey	1	0
Not exposed	1	6
Sandstone, medium-grained	3	0
Shale, grey		3
Coal		1
Fireclay, shaly	2	0
Limestone, impure grey (weathering red); ostracods and bivalves		4
Shale, grey calcareous		6

[4971 7753]:

	ft	in
Sandstone, shaly towards base		2
Not exposed	4	6
Shale, grey	2	0
Limestone, fine-grained crystalline	1	0
Shale, hard calcareous		4
Shale, dark calcareous; limestone balls		6
Not exposed	2	0
Limestone, dark grey nodular impure		6
Shale, dark; plants	1	6
Limestone, dark nodular; rare *Spirorbis sp.*		6
Shale, micaceous, and sandstone	1	3
Limestone, fine-grained brown-weathering; black chert inclusions	4	6
Sandstone, calcareous		4

[4970 7758]:

	ft	in
Sandstone, fine-grained mottled current-bedded	1	0
Not exposed	6	0
Limestone, flaggy; microfossils		3
Not exposed	2	6
Shale, hard sandy calcareous		3
Limestone, grey cherty		6
Shale, hard calcareous		1
Limestone, fawn-grey cherty		9

[4966 7767]:

	ft	in
Limestone, fine-grained grey		4
Shale, grey soft		4
Limestone, fine-grained		1½
Shale, hard dark	1	3
Limestone, dark grey impure; fish debris, bivalves and plant debris		6
Limestone, dark grey fine-grained		9
Shale grey		9
Limestone, fine-grained nodular impure	1	0
Shale, grey sandy		9

[4962 7777]:

	ft	in
Sandstone, grey stained red, coarse, many shale pellets	4	0
Fireclay-mudstone, grey, sandy at top	11	6
Fireclay, grey, partly stained purple	7	0

There is a considerable gap between the highest beds seen in the Sleet Beck and the lowest beds exposed farther south in the River Black Lyne.

West of Sleet Beck, rocks of Middle Border Group age crop out in the core of an anticline and are bounded to south and west by the curving crop of the Clattering Band and to the north and east by the Parkhouse and Dappleymoor faults respectively. The solid rocks are extensively covered by drift, and both Chamot and Wakey hills are thickly forested; the only exposure is along a 200-yd stretch of a small stream about 600 yd S.E. of Chamot Hill where sandstones, shales and two thin crinoidal limestones dip at about 50° to 60° to south-east.

WHITE LYNE CATCHMENT

River White Lyne (loc. 48). Middle Border Group strata dipping a little to the north of east at angles of 85° or more are traversed down-dip by the River White Lyne so as to reveal a continuous section about 1100 ft thick. Apart from a few minor gaps this represents a complete sequence from the assumed position of the Whitberry Band up to the Clattering Band. There are a number of minor easterly tear faults, but it has been possible to correlate across all except one of them. The beds are, for the most part, deeply and uniformly reddened by a secondary process which probably accounts for the absence of coals. The sequence is shown graphically in Fig. 18 and a detailed description may be found in Appendix I (p. 311). Much of the section is only accessible during drought conditions, and the attitude of the beds makes collecting difficult.

The Whitberry Band has not been seen although the type locality is only ¾ mile to the north-east. However, its position is believed to lie just above the top of a thick bed of shale and marl [5109 7320] in which a single specimen of *Chonetes*? was found, together with bivalves and ostracods. At the junction of this thick shale sequence with the overlying sandstone is a thin double row of algal nodules, and 25 ft higher *Antiquatonia teres* was obtained from shales lying immediately above a thin limestone [5108 7325]; this is the highest record of *A. teres* in the White Lyne section.

Above it is a poorly exposed succession, consisting of several hundred feet of marls, sandy shales, sandstones and thin limestones. One of the limestones, 15 yd downstream from the previous locality, is a splintery, porcellanous rock, 2½ ft thick, which seems to have resisted reddening except for the topmost 3 in. Still higher in the sequence shales in the roof of one of a group of several thin limestones [5102 7329] have yielded abundant *Lithostrotion sp.* with cerioid tendencies and possibly akin to *L. martini;* it is the only record of the genus below the Clattering Band.

The shales containing *Lithostrotion* are overlain by about 150 ft of predominantly arenaceous strata which are the lateral equivalents of more massive sandstones cropping out at, and downstream from, the road bridge at Whitberry Burn. Calcareous shale with *Fenestella* cf. *matheri* occurs in the middle of this sequence.

Still higher in the succession *Limipecten sp.*, *Myalina sp.* and *Sanguinolites plicatus* have been obtained from a 7½-ft limestone [5095 7335]. About 45 yd downstream (measured in the north bank) from the limestone a strike-slip fault interrupts the sequence; the direction of throw is dextral, the amount unknown, but believed to be small. Sandstones cropping out on either side of the fault may possibly belong to the same bed. In the left bank the beds are much shattered and veined adjacent to the fault.

The topmost 160 ft of the Middle Border Group sequence consists mainly of shales with a number of thin limestone bands and three sandstone posts which are the attenuated equivalents of the Oakshaw Sandstone. The highest sandstone is overlain by the Clattering Band which is represented by 30 ft of red marls containing abundant *Lithostrotion martini* in association with *L. portlocki*, *Semiplanus sp. nov.* and *Productus garwoodi.*

Whitberry Burn. The Whitberry Band is well exposed in the south bank of the burn [5203 7408] and is overlain, between this locality and the road bridge 115 yd upstream, by just over 430 ft of measures which dip steeply to the west-north-west. These beds lie to the east of the Lyneholmeford Fault-belt, which here probably passes a little to the west of the road bridge. The section is as follows:

	ft
Sandstone, whitish, fine- to medium-grained, saccharoidal, poorly micaceous: highest beds under road bridge	120
Not exposed; probably flaggy sandstone and shale	90
Limestone, yellow-weathering, sandy [5199 7408]	3
Shale; sandstone bands and one thin limestone	14
Not exposed	20
Sandstone	1
Not exposed	3
Limestone, sandy	1
Sandstone	3
Shale, sandy; thin fireclay near top [5200 7409]	9
Sandstone; worm tracks on undersides of bedding planes	3
Shale, sandy at base	5
Limestone, grey	¾
Sandstone	8
Not exposed	4
Sandstone	2
Not exposed	5
Sandstone	6
Limestone	⅔
Shale	1½
Sandstone, flaggy	2
Shale	1½
Limestone, earthy	3
Sandstone, flaggy; shaly ribs ..	10
Limestone, grey-brown earthy [5201 7409]	18
Shale and sandstone	6
Limestone, grey earthy	2
Shales, sandy; sandstone bands ..	30
Shale; calcareous ribs; brachiopod debris	7
Sandstone, flaggy	5
Shale, calcareous; thin limestone at base	11¼
Shale, sandy, grading up into sandstone	10

	ft
Limestone; small productids and *Composita sp.* (loc. 49b)	½
Shales, sandy; calcareous ribs . .	4
Sandstone, flaggy; grading down to sandy shale	10
WHITBERRY BAND (loc. 49a)	
Shale, calcareous; abundant *Rugosochonetes cumbriensis* . .	5
Shales, sandy at base; rare *R. cumbriensis*, *Aviculopecten* and *Derbyia*	7

The 6-in limestone 14 ft above the Whitberry Band is the equivalent of the Spadeadam Limestone farther east (p. 94).

Parkfoot Sike. The name Parkfoot Sike is here given to the stream which rises in the neighbourhood of Badds [5130 7410], and flows westwards and southwards through High Parkfoot [5088 7366] to enter the River White Lyne [5050 7328]. In the section 200 yd S.W. of Badds more than 100 ft of non-reddened sandstones and sandy shales are exposed intermittently: through one of the gaps in the sequence runs the crop of a coal seam [5117 7400], formerly worked and said to be about 1 ft thick. The measures are vertical and lie directly on the strike of the Middle Border Group beds in the White Lyne. The Goat Island–Lyne Thrust passes nearby to the north.

Show Burn. North-east of Allergarth [5300 7141] the upper part of Show Burn traverses rocks of Middle Border age. The Whitberry Band is exposed at two localities [5325 7194; 5383 7201] separated by an east-north-easterly fault, but little can be seen of the deeply reddened overlying measures. A thin limestone is faulted against sandstone to south [5329 7186]. There are several exposures of sandstone in the stream N. by W. of Rooms Crag Cottage, and the crag itself [5357 7160] consists of 5 ft of massive sandstone with contorted bedding. There are several old shallow quarries nearby.

Between the Antonstown and Round Crag faults. To the north of White Preston [5936 7705] and the Antonstown Fault many of the great crags along the higher fells are formed by Middle Border Group sandstones. They include Red Skirts, Rushy Crag, Round Crag and Slaty Crag, as well as Long Crag, the crest of which extends for three quarters of a mile north-north-east to form the topographic divide between the Lyne and Irthing catchments.

The Whitberry Band is not exposed in this area, but a limestone just above it—probably the Spadeadam Limestone of the area farther south (p. 94) and the 6-in limestone of Whitberry Burn—can be traced by means of sink holes. Exposures are otherwise limited to the sandstone crags, and the estimated thickness of the group hereabouts is 1500 ft. The northward thickening which this implies may reflect the beginning of a contemporaneous downwarping along the line of the Antonstown Fault which became more pronounced in Upper Border Group times (p. 108).

Between the Round Crag and East Christianbury faults. The sandstones which crop out at Round Crag and Long Crag, south of the Round Crag Fault, form Tod Crag and the Long Bar farther north. Tod Crag is affected by a small fault trending east-south-east sub-parallel to and a short distance to the south of Muckle Hare Grain where the slickensided fault-scarp can be seen on the hillside [5856 8017]. In Muckle Hare Grain the Whitberry Band is exposed near the top of a thick sequence of shales [5850 8027]. Farther upstream, at the base of the Tod Crag Sandstone, is a thin limestone [5863 8024], while 270 yd to the south-south-east the following section [5883 8009] crops out against the small fault referred to above:

	ft
Shale	–
Limestone, sandy detrital; algal nodules	4
Shale and sandstone	6
Limestone	1
Shale; weathering yellow, banded	2

The Whitberry Band crops out in the Rough Grain [5881 8106 loc. 50]; where it overlies 18 ft of Cambeck mudstones (p. 76) and is represented by 3 ft of brown shale with sandy bands and *Ovatia bioni*, *Rugosochonetes cumbriensis* and *Streblochondria*? It is succeeded by the local equivalent of the Tod Crag Sandstone, which is massive, mainly fine-grained and current-bedded, with contorted bedding developed locally [5898 8109]. The same sandstone forms Twolads and Middle Crags, respectively south and north of the Grain. Farther east, the Rough Grain Fault crosses Rough Grain [5980 8110] and an east–west basalt dyke is terminated against it. Still farther upstream the Grain follows the line of the fault and there are discontinuous exposures of sandstones, some greenish and shattered, on both banks. A few bands of yellowish impure cementstone also crop out together with coal smuts and a 1-in coal in a shale on the east side of the fault [5961 8122]. The highest exposed beds [5963 8122] are green nodular shales overlying a foot or more of green flaggy sandstone containing nodules, possibly of algal origin.

The Whitberry Band is also exposed [5836 8132] 40 to 50 yd W. of Gate Grain, and the Middle Crag Sandstone crops out farther north [5843 8140 to 5854 8170] beneath much boulder debris. One of the few exposures higher in the stream consists of a foot or more of impure limestone [5863 8196]. The sandstone forming Hangingstone Crag is 18 ft thick and is terminated to the west by the East Christianbury Fault; it is the same bed as that which forms the Long Bar 1 mile to the south-east.

The crags of Long Bar are said to have provided the stone for the Anglian Cross in the churchyard of St. Cuthbert's Church at Bewcastle. At outcrop this sandstone has a system of rectangular joints so that on weathering it tends to break into roughly rectangular blocks, some of which are pock-marked in a fashion resembling artificial working by chisels. It thus seems unlikely that a similar pock-marked rectangular block [5925 8071], locally reputed to be the 'brother' of the stone which now forms the monument, was in reality quarried. J.B.W.D.

Burnt Tom Crags and headwaters of Yett Burn. Burnt Tom Crags [around 595 819] are formed by two 10-ft beds of sandstone separated by about 20 ft of unexposed strata. The sandstones are fine-grained and quartzitic with irregularly contorted bedding.

Between the East Christianbury and Rough Grain faults, the line drawn on the map for the top of the Middle Border Group is arbitrary. Strata assigned to the group are visible only in disconnected exposures in the highest reaches of Yett Burn: they are mostly fine-grained flaggy sandstones and silty shales. Carbonaceous shale is poorly exposed [5939 8249] 1 mile E.N.E. of Christianbury Crag; a thin bed of fine-grained calcareous sandstone with shell debris crops out [5951 8257] 150 yd farther downstream. D.H.L.

CAM BECK–KING WATER CATCHMENT

Cam Beck. Reddened beds, almost certainly of Middle Border age, crop out in the Cam Beck between the Low Park Fault [5412 6937] and the base of the Trias [5358 6910]. They consist mainly of sandstones, with a few shales and a single limestone at least 6 in thick [5400 6927].

Green's Burn (loc. 51). Near Spadeadam Farm the Whitberry Band occurs near the base of a thick series of fossiliferous shales called 'Spadeadam Beds' by Garwood (1931, pp. 115–7), who regarded their fauna as the 'impoverished representative' of the Arnside *Michelinia* Zone, high within the C_2 Zone of Westmorland. The shales are about 60 ft thick, and are overlain by the Spadeadam Limestone (loc. 51a), which contains *Composita ambigua*, and is probably equivalent to the thin limestone overlying the Whitberry Band at the type locality (p. 93). In Green's Burn it is exposed at two localities. At one of these [5830 7030], 130 yd S.W. of the ford, it consists of 4 ft of hard grey fossiliferous limestone and is overlain by 3 ft of calcareous sandstone; at the other [5823 7026], where the section is repeated by the Shopford Fault, it comprises 15 ft of fossiliferous calcareous shale overlain by 2½ ft of hard sandy limestone and 5 ft of calcareous sandstone. Near the ford the Spadeadam Limestone is overlain successively by several feet of platy shale, about 10 ft of sandstone and an 18-in limestone. In addition to the species recorded from the Spadeadam Beds by Garwood (op. cit., p. 116) *Echinoconchus* cf. *punctatus* (J. Sowerby) was collected during the resurvey. The crops of the Whitberry Band and the Spadeadam Limestone strike north-north-eastwards from Spadeadam Farm and associated beds are exposed in the small stream immediately behind the north of the farm. North of the Caudbeck Fault [5902 7924] the Spadeadam Limestone may be represented by a flaggy ostracod limestone, 2 ft thick, but still farther to the north-east, these beds are hidden by drift. In a tributary of Green's Burn [5882 7057], 270 yd E.S.E. of Spadeadam Farm, measures slightly higher in the sequence are exposed as follows:

	ft
Limestone and calcareous mudstone	2
Shale with limestone ribs; *Girvanella moorei*?, *G. staminea* and *Ortonella kershopensis*	2
Mudstone; plants	3

Craig Burn. The lowest beds seen in Craig Burn [5604 6859] lie well above the base of the Middle Border Group; they include a 2-ft limestone underlain by sandstone and overlain by 3 ft of grey shale with limestone bands.

At Craigburn Bridge and for a distance of 275 yd to the west are several exposures of sandstone and shale: mudstones [5627 6867] have yielded bivalves and ostracods.

Between Craigburn Bridge and the road leading north to Spadeadam Farm three persistent sandstone crags emerge from the drift and can be traced for more than a mile along the strike. The crags are 30 to 50 ft high and are separated by beds less resistant to weathering, probably shales. The crop of the middle sandstone can be traced across the Spadeadam road, where it has been quarried as far to the north-east as the Caud Beck Fault: it is exposed in a small stream just south of the fault [5916 7067].

Stone Beck. More than 80 ft of beds belonging to the upper part of the Middle Border Group are exposed in Stone Beck as follows:

	ft
Limestone, massive sandy [5802 6853]	1½
Ironstone, calcareous	½
Sandstone, massive	7
Not exposed	5
Shales, sandy	1½
Sandstone, massive	3
Shales	5
Cementstone, sandy	1
Not exposed	9
Sandstone	1
Shales; rare algal nodules; *Plagioglypta sp.* and *Leiopteria divisa* [5804 6868; loc. 52a]	8
Shale, algal	½
Limestone; large algal nodules ..	1½
Mudstone, algal	½
Mudstone, shaly	1⅓
Limestone	¼
Shales, sandy	6
Sandstone, flaggy	5
Shales, sandy; *partly obscured* ..	6
Sandstone, calcareous	1
Not exposed	4
Sandstone at junction of two streams: affected by 1-ft fault ..	4
Shales, calcareous with thin nodular limestone; *Girvanella staminea, Ortonella furcata* [5805 6880; loc. 52b]	5
Sandstone, massive, irony ..	2⅔
Limestone, thin sandy	½
DUMBLAR RIGG SANDSTONE	
Massive sandstone in westerly tributary [5800 6880]; for petrography see p. 215	6

Farther downstream Stone Beck flows south-westward across the strike and the section is repeated. Beds lower than the Dumblar Rigg Sandstone include 1 ft of

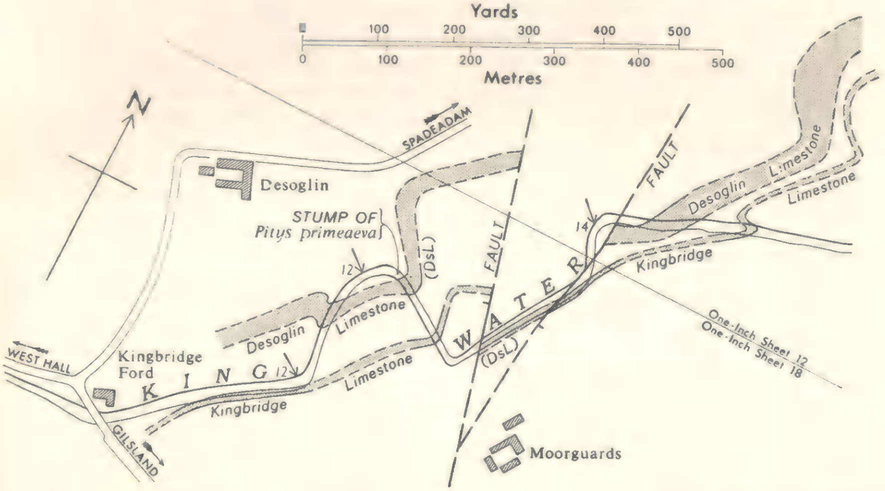


FIG. 20. *Sketch-map showing outcrops of the Kingbridge and Desoglin limestones near Kingbridge Ford*

limestone overlain by 1 ft of calcareous shale [5759 6828 and 5737 6795].

King Water (Lower). The topmost beds of the Group can be seen in a series of excellent strike sections extending for 2 miles along the King Water between Kingbridge Ford in the Brampton (18) district and the mouth of Trout Beck. According to Trotter (*in* Trotter and Hollingworth 1932, pp. 29–32) they include, within a total thickness of 100 ft, four limestones named in ascending order Cementstone, Productus, Lamellibranch and Martini. The form referred to as *Productus θ* in the Productus Limestone, however, is now identified as a small species of *Linoproductus* and this limestone can now be shown to be the same bed as the Lamellibranch Limestone; moreover, the latter does not pass laterally into shale as stated by Trotter (op. cit. p. 30). The Kingwater Beds of Trotter thus consist merely of the Desoglin Limestone below (equivalent to the Cementstone and Productus-Lamellibranch limestones) separated by 16 ft, mainly of shales, from the Kingbridge (formerly Martini) Limestone above.

The most complete section occurs just beyond the southern margin of the Bewcastle district upstream from Kingbridge Ford Farm and east of Desoglin (Fig. 20). It is as follows:

	ft	in
Sandstone, massive, forming crag [5802 6779]	10	0
Not exposed probably shale ..	6	0
KINGBRIDGE LIMESTONE		
Limestone, hard grey; colonies of *Lithostrotion martini* in positions of growth	2	6
Shale, dark grey; abundant *L. martini*	1	4
Limestone, grey	1	6
Shale		8
Limestone, lenticular rib ..		3
Coal		1
Shale, dark carbonaceous ..		9
Coal		4
Seatearth, merging downwards into sandy shale	1	6
Sandstone, flaggy grey	1	6
Shale, dark; thin fossiliferous limestone ribs	6	0
Shales, grey silty with calcareous nodules	5	0
DESOGLIN LIMESTONE		
Limestone, nodular at base; *Linoproductus sp.*	2	0
Shales, calcareous; ostracods	3	6
Limestone, yellow and blue-grey weathering, wavy-banded; unfossiliferous	1	0
Shales	4	6
Sandstone, fine-grained, grey, and sandy shale in alternating bands	10	0
Shales with bands of nodular limestone	12	0
Ganister, impure	2	6
Shale, dark; rare bivalves and algal nodules	3	0
Limestone, impure brownish; alga-encrusted bivalves ..	1	6
Shale, dark; bivalves, ostracods and yellow-weathering nodules [5800 6778]	2	0

The horizon of the *Pitys primaeva* bed of the Spadeadam area lies about 14 ft below the Desoglin Limestone; one small specimen of *P. primaeva* can be seen in the bed of the river near the left bank [5803 6778].

Farther upstream the Desoglin Limestone crops out in and along the bed of the river between two faults (Fig. 20). Within this fault block, sandstones, shales and thin coals cropping out at a bend in the river [5822 6794] appear to lie at a lower stratigraphical level than the lowest beds seen downstream. Beyond the easternmost of the two faults is yet another exposure of the Desoglin Limestone, readily distinguished by the colour of its basal 'cementstone' member. The fauna of the upper part of the limestone is more varied than it is downstream: it includes crinoid debris, gastropods, bivalves and *Punctospirifer sp.* Still farther upstream [5839 6803] the Kingbridge Limestone is again exposed.

The Upper Border Group strata (p. 124) cropping out above the Kingbridge Limestone are cut off about ⅔ mile upstream by the North Upper Denton Fault [5938 6832], beyond which the Kingwater Beds are repeated. The Desoglin Limestone is exposed in the right bank of the river [5949 6839] near the Holy Well where the section is:

	ft
Limestone, hard, banded grey and yellow, particularly in lower half ..	7
Shale, calcareous	2
Limestone, fine-grained, yellow and grey banded	1
Shale	3

Both leaves of the limestone here have assumed the colouration and banded appearance peculiar to the lower leaf at Kingbridge Ford. There are two more exposures on either side of a bend in the river [5965 6857], where the overlying beds include a 3-in coal.

Beds below the Kingbridge Limestone are poorly exposed in the river east of Highstead Ash, between two branches of the Waterhead Fault. The following section, which lies below the Desoglin Limestone, can be seen in the right bank [6015 6944], 270 yd N.E. of Highstead Ash:

	ft
Sandstone, flaggy	3
Shale, sandy	6
Limestone	½
Shale	1
Sandstone, calcareous	1½
Sandstone and shale in alternating bands	4
Sandstone, massive	4

One further exposure of the Kingbridge Limestone is seen in the King Water [6114 6991], 320 yd upstream from the mouth of the Trout Beck, where the top of the bed is affected by a minor northerly fault. Between this locality and the northern branch of the Waterhead Fault, half a mile downstream, underlying beds are exposed dipping gently to the south-east. The section in the river is supplemented by additional exposures in the Trout Beck. The Desoglin Limestone crops out at a ford [6101 6986] where the section is:

	ft
Sandstone, jointed flaggy calcareous	2
Not exposed; some calcareous shale	3
Limestone, hard, fine-grained; yellow blue-banded	1¼

Downstream from the ford, the limestone is underlain by 12 to 14 ft of alternating sandy shales and flaggy sandstones. Sandstones near the top of this sequence thicken locally and enclose large nodular masses of calcareous mudstone with calcite-filled desiccation cracks. At the base of the same sequence are several feet of micaceous flaggy seatearth or impure ganister in which are rooted—still in positions of growth—ten stumps of *Pitys primaeva*. They are described with reference to Fig. 21a as follows: No. 1 has a maximum diameter of 5 ft; no carbonaceous material is visible and the exterior weathers to a brownish orange colour. No. 2 has a maximum diameter of 8 ft 2 in, excluding buttress roots which extend outwards at the bole for a further 1 ft 6 in and which can be seen emerging from the seatearth just below water level; partial rotting has caused some external fluting of the trunk (Fig. 21c). No. 3 has a maximum diameter of 3 ft 6 in; no buttress roots visible, but brownish pink rooty sandstone is piled up against its western side. No. 4 has a maximum diameter of 5 ft 6 in and has some external carbonaceous material. No. 5 has a maximum diameter of 2 ft 3 in, but has no visible carbonaceous material. No. 6 is circular and is 4 ft 10 inches in diameter. No. 7 has a maximum diameter of 3 ft 4 in; rooty sandstone and sandy seatearth are piled up against the eastern side and carbonaceous material adheres to sides of fissures in the trunk. No. 8 has a maximum diameter of 3 ft 3 in, and has patches of carbonaceous material adhering to the exterior of the trunk; sandstone against the bole is partially reddened and rumpled. No. 9 has a maximum diameter of 2 ft 9 in, and has reddened sandstone adhering to the exterior of the trunk. No. 10 has a maximum diameter of 6 ft 6 in, and has been partially excavated in shale and sandstone to 7 ft 6 in below top without reaching the base; when seen in 1962 part of the trunk had slipped several feet down the bank.

The cellular structure of the wood is obvious on weathered surfaces: in thin section (E 27371–5)[1] it is seen to be perfectly preserved in dark grey dolomite with a little calcite—a lithology closely resembling that of the lower part of the Desoglin Limestone. The woody cells are 0.05 to 0.1 mm in diameter, and the cells of the elongate medullary rays, which are plentiful and lie at a high angle to the rest of the wood, are about 0.35 mm in diameter. Some of the cells are filled with dark, opaque, probably carbonaceous material. The exterior margins of the stumps are formed by buff-coloured silty limestone composed of angular quartz grains (0.02 to 0.05 mm) in a groundmass of fine-grained, turbid, partly recrystallized and spherulitic calcite, with many patches of opaque carbonaceous material and scattered grains of pyrite.

It is inferred that the upright, rotting trunks

---

[1] Numbers refer to thin sections in the English Sliced Rock Collection of the Institute of Geological Sciences.

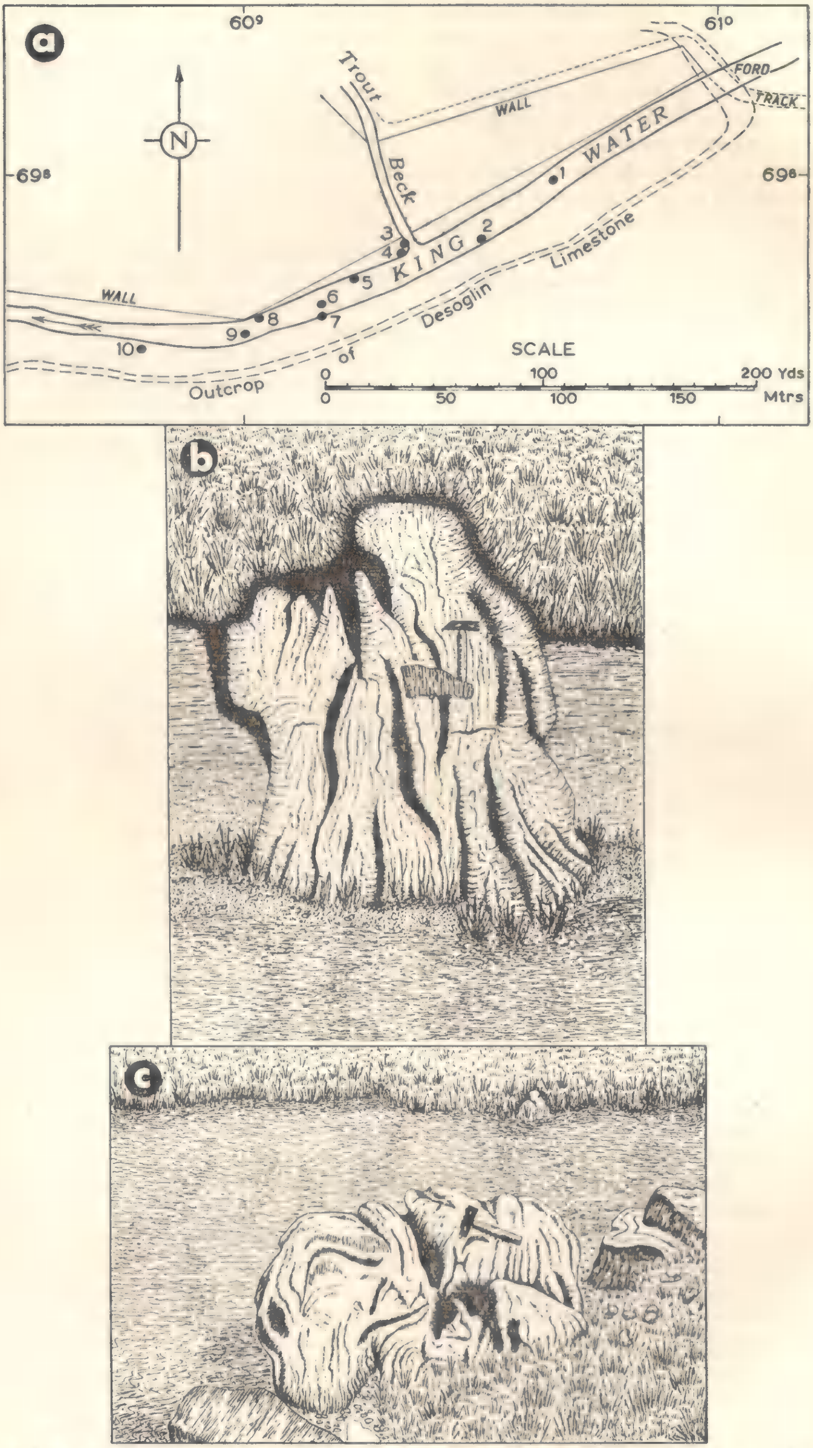


FIG. 21 *Sketch-map and drawings to illustrate the occurrence of* Pitys primaeva *stumps in the King Water. (a) Locality map. (b) Sketch from the side of stump No. 10, partly excavated in the left bank, (c) oblique sketch of stump No. 2; the seatearth in which the tree is rooted lies just below water level*

had not been completely buried by sediments when the Desoglin Limestone was formed, so that lime-rich mineralizing solutions then gained access through cracks and fissures from the tops to lower parts of the trees.

In the King Water, little is seen of the measures below the *Pitys primaeva* bed, except for four thin, impure limestones [6062 6977 to 6072 6974]. This part of the sequence is better seen in Trout Beck.

Trout Beck. The holotype of *Dyscritella nana* Lee was collected during the original survey from 'Trout Beck, just below Dumblar Rigg', but its exact position is uncertain (loc. 53). Garwood (1931, pp. 119, 157) obtained his specimens from shale and limestone [6077 6995], 200 yd N.W. of the mouth of Trout Beck, where the section is:

	ft
Limestone, impure (near top of bank)	2
Not exposed	6
Sandstone, with large cracked and veined nodules	6
Shale, calcareous; abundant *D. nana*, *Punctospirifer sp.* and bivalves towards the base	20

A fault cuts the stream a few yards north of this locality, and on its far side [6079 7004] —below the horizon of the *Dyscritella* shales —lies the following section:

	ft	in
Coal		4
Shale and fireclay	1	0
Not exposed	5	0
Shale, planty	2	0
Limestone		8
Coal		3
Shale, dark; planty	3	0
Cementstone; plant traces	2	6
Shale, carbonaceous, and fireclay	7 in to 8 in	
Coal		6
Shale; plant remains		5
Sandstone		4

The strata immediately upstream from this locality are masked by drift, but 110 yd S.S.E. of Dumblar Rigg the topmost beds of the following section are exposed, whilst the lowest beds occur in the stream due east of the farm:

	ft
Shales, calcareous; ostracods	3
Limestone, impure; bivalves	¾
Shale	1½
Not exposed	5
Limestone, weathered yellow; small algal nodules (probably the lower algal bed of Stone Beck)	¾
Not exposed	8
Sandstones, massive; forming waterfall	30
Not exposed	3
Shale and flaggy sandstone, with some fireclay	8

Farther upstream [6063 7041], 80 yd E.N.E. of the farm, the following beds are exposed:

	ft
Shale	3
DUMBLAR RIGG LIMESTONE	
Limestone, shaly; ostracods	1½
Limestone, weathered yellow, dolomitic	1¾
Limestone, shaly impure, and calcareous shale	1½
Limestone, fine-grained grey compact; plant remains and a few ostracods	1

The lowest strata seen in this stream consist of 20 ft of sandstone [6071 7077].

Middle Shield Beck. The lowest measures in Middle Shield Beck crop out [6170 7070], 170 yd W. of Middle Shield Farm, and consist of:

	ft	in
Sandstone, massive; forming a waterfall	6	0
Cementstone, weathered yellow	1	3
Coal, shaly		3

Slightly higher beds, consisting of about 20 ft of shaly mudstone containing bands of large dolomitic limestone concretions with shrinkage cracks, crop out 170 yd S.W. of the farm. The Desoglin Limestone does not crop out, but the Kingbridge Limestone is exposed in the bank [6170 7030], where it is underlain by fossiliferous shales with thin limestone bands.

Spadeadam No. 1 (Middle Shield) Bore [6164 7041, loc. 55], 380 yd S.W. of the farmhouse, provides an excellent section of the uppermost beds of the Middle Border Group (Appendix II, p. 329 and Fig. 18). It met a limestone some 26 ft below the Dumblar Rigg Limestone which is not known at outcrop.

King Water (Upper). The Desoglin Limestone is again seen in the right bank of the King Water [6305 7194], where the section is:

	ft
Sandstone, flaggy, alternating with shale	6
Sandstone, rooty flaggy	1

	ft
Limestone, sandy (or calcareous sandstone); shelly, crinoidal; contains some carbonized plant material	2½
Sandstone, flaggy	1
Shale, sandy	⅔
Not exposed	⅓
Sandstone, rooty calcareous; faulted against shale and fireclay with sandstone ribs	1½

The limestone has not the banded appearance which distinguishes it downstream (p. 97). Upstream from this locality are scattered outcrops of sandstone, and one of these beds, 12 ft thick, forms a waterfall [6296 7198] and is underlain by 25 ft of shale with thin limestone bands. Above the junction of the river with Caud Beck, shales, fireclays and a thin coal are exposed [6290 7225], together with part of the Jerrycalf Limestone [6295 7231]. This limestone is seen better in the King Water about 60 yd upstream from the junction with Jerrycalf Sike, where it is a fossiliferous, hard, crystalline bed, 2½ ft thick.

Garwood (1931, p. 119) records *Punctospirifer ashfellensis* [= *P. scabricosta*] and *Productus corrugatohemisphericus* from this horizon. Other forms collected during the resurvey [6309 7255; loc. 54a] include *Composita* cf. *ambigua*, *Ovatia* aff. *bioni* as well as the algae *Girvanella ducii*, *G. staminea* and *G. sp. nov.* About 150 yd upstream, a dolomitic nodular band in sandstone has yielded *Girvanella sp. nov.* and *Rhabdomeson sp.*

LOWER IRTHING CATCHMENT

Butter Burn. Beds a short distance above the Whitberry Band [6114 7421, loc. 56a] are exposed intermittently in the north–south stretch of the Butter Burn, west of Butterburn Hill. They include 2 ft of shelly crinoidal limestone, from which *Girvanella staminea* and *Composita sp.* have been collected (loc. 56b). About 130 yd downstream [6123 7405] on the downthrow side of a small fault, the following section is visible in the left bank:

	ft
Sandstone, massive (forming crag)	8
Not exposed; some calcareous sandstone debris	25
Sandstone, fine-grained white ..	1
Not exposed	4 to 5
Shale	¾
Shale in alternation with current-bedded sandy grey crystalline limestone (loc. 56c); *Girvanella ducii*, *G. staminea*, *Koninckopora inflata* and *Syringothyris sp.*	5
Limestone, flaggy detrital finely crystalline; bedding planes packed with crinoidal debris, rare brachiopods, tiny turreted gastropods and bivalves; some *Girvanella staminea*	3½

Some 200 yd farther downstream, between two faults, 2½ ft of almost horizontal detrital limestone are exposed [6115 7388]; detrital limestone is further visible in the left bank [6110 7384] on the south side of one of the faults. South of this locality exposures are intermittent and consist only of sandstone.

Spadeadam No. 4 (Grey Mare Hill) Bore [Appendix II, p. 338] cut 450 ft of beds belonging to the lower half of the Middle Border Group. They consist almost entirely of sandstones, argillaceous sandstones and sandy shales with no limestones or any fossiliferous horizon.

UPPER IRTHING CATCHMENT

Tarn Beck. Measures at or near the top of the group are disposed in a broad synclinal basin with an east–west axis, bounded to north and south by the Black Stantling and Antonstown faults respectively, and drained by the Tarn Beck and its tributaries. Thick, massive sandstones, sporadically greenish and chloritic, are exposed in the headwaters of the Tarn Beck (Raeholes Sike and Rotten Grain) and are rather lower in the succession. Algal beds crop out in the Tarn Beck [6057 7850] near the mouth of Crossy Cleugh where the following section can be seen, mostly in the left bank:

	ft
Shales, compound algal nodules up to about 2-in diameter	8

	ft
Shales, with a 3-in carbonaceous band	1¼
Limestone, yellow-weathering; worm-tracks	½
Shales, sandy; thin coal band ..	4
Sandstone, massive, forming waterfall	5
Shale, sandy, nodular	3
DUMBLAR RIGG SANDSTONE	
Sandstone, greenish	2

The feature made by the Dumblar Rigg Sandstone sweeps round from the base of this section in a broad arc north and south of the Tarn Beck. To the north it forms the mass of Black Stantling and the somewhat 'slabby' crag about ¼ mile to the south-south-west: to the south, Long Linn and Tod Crag emerge to a maximum height of about 25 ft above the encircling peat.

The following section has been measured in Stantling Burn, south of the Black Stantling Fault:

	ft
Sandstone [6080 7919]	6
Shale, sandy; plant debris.. ..	6
Limestone, weathered yellow ..	4
Shale, with thin coal	1
Not exposed	6
Sandstone, massive	18
Shales; carbonaceous bands; yellow-weathering decalcified 'famp' bed	15
Shale, sandy; limestone balls ..	5
Sandstone, flaggy and sandy shale	3
Shale	1⅓
Limestone	⅔
Shale	1¼
Limestone	¼
Shale, calcareous; abundant compound plate-size algal masses [6070 7963]	¼
Shale, ostracods	4
Limestone, bright orange-weathering	¾
Shales, calcareous at top	2½
Sandstone, flaggy	3
Shale, sandy; calcareous band at top, greenish at base	7
DUMBLAR RIGG SANDSTONE [6066 7973]	
Sandstone, greenish	2

Just north of the fault there is an isolated exposure [6050 7998] of limestone with several feet of calcareous shale containing algal material; these beds probably lie very near the top of the Middle Border Group.

J.B.W.D.

About 2½ miles to the south-east, a sandstone crops out to form Tom's Crags [6384 7813], a rocky cliff on the east bank of the River Irthing, 510 yd N.N.W. of Paddaburn Farm. It is about 150 ft below the top of the Middle Border Group and is the highest member of the following measured section:

	ft
Sandstone, thickly-bedded fine-grained; casts of plant stems ..	12
Clay, pale green (?weathered shale)	4
Mudstone, greenish brown sandy; thin sandstone bands	3
Not exposed	2
Mudstone, green; plant fragments	1
Sandstone, green fine-grained argillaceous; locally rooty	1
Not exposed	4
Mudstone, grey-green sandy; an 8-in band of argillaceous sandstone	6⅓
Sandstone, grey-green fine-grained argillaceous; sparingly micaceous	2⅔
Siltstone, brown thinly-bedded calcareous	6
Not exposed	12
Sandstone, green thinly-bedded fine-grained..	1
Mudstone, green (*only seen in part*)	1¾
Mudstone, grey hard rooty ..	1
Not exposed	10
Mudstone, yellow-brown calcareous, and sandstone, green thinly-bedded fine-grained, interbanded; jointed	3
Not exposed; (in part mudstone)..	12
Sandstone, greenish thinly-bedded micaceous	8
Sandstone, greenish irregularly bedded knobbly, fine-grained below, coarser at top [6374 7818]	12 to 13
Sandstone, banded grey and green; strongly jointed (in river bed) ..	4

The lowest sandstone crops out 300 yd below the confluence of the Pikeburn. A further 80 yd upstream a highly jointed, crushed and slickensided, greenish sandstone is traversed by a north-north-easterly fault. Immediately upstream of the fault, shales overlie flaggy, highly jointed, banded grey and green, fine- to medium-grained sandstones, becoming progressively more massive to base [6359 7827].

...VERSITY ... 1970

The sandstone forming Tom's Crags is cut off 40 yd to south by a north-westerly fault. On its southern, downthrown, side, 6 ft of fine-grained thin wispy-bedded sandstone are exposed. Small exposures, consisting of greenish-grey thinly-bedded sandstone, strongly jointed, and locally containing calcareous concretions, are present on the west bank of the river farther downstream. These beds are cut off by a north-easterly fault, 430 yd N.W. of Paddaburn Farm.

D.A.C.M.

WHICKHOPE BURN CATCHMENT

Back Burn. On the south bank of Back Burn, 1530 yd E.N.E. of Broomylinn, the following section is exposed [6450 8471]:

	ft
Shale, grey; partings of sandstone and silty shale; 12-in bed of grey calcareous sandstone	18
Sandstone, grey brown-weathering fine-grained calcareous; in beds up to 18 in thick, with thin shale partings; fossil debris	12
Sandstone, massive fine-grained ferruginous	4½
Not exposed	4
Sandstone; partially seen in stream bed	2

On the hillside south of Back Burn, several sandstones make rocky scarps which may be traced down to the burn but, since no solid rock is seen on the left bank, rock-head is presumed to descend below stream-level in a drift-filled valley. On the right bank [6463 8486], almost 1 mile E.N.E. of Broomylinn, are 20 ft of sandstone, massive below and thin-bedded above. A higher sandstone, about 45 ft thick, is exposed 200 yd downstream [6474 8498]: it is thick, false-bedded and fine-grained.

North of Back Burn exposures are small and widely separated; they are mostly of sandstone, though a few are of green or purple mudstones.

Binky Burn. Below its confluence with Humble Burn, Binky Burn flows through a gorge 200 ft deep, in which the following section of Middle Border Group strata is exposed [6607 8414 to 6612 8459]. The strata dip northwards at 12°, and are cut off on the south by the Beckhead–Binky Linn Fault. The fault face makes a cliff about 25 ft high and 70 yd long in the lowest sandstone of the section.

	ft	in
Sandstone, fine-grained [6612 8459]	4	0
Shale, grey; *poorly exposed* . .	8	0
Sandstone, grey, brown-weathering, thickly-bedded fine-grained; slightly calcareous in lower part	6	0
Shale, grey; sparingly micaceous; a few shell fragments	5	0
Coal, rather shaly		4
Shale, carbonaceous		4
Shale, grey micaceous; some thin fine-grained sandstone partings; rooty at top	20	0
Sandstone, flaggy fine-grained; partly calcareous; shale partings	10	0
Not exposed; probably shale about	6	0
Sandstone, brown thickly-bedded fine-grained; thickens southwards	10 to 20	0
Not exposed; shale debris; carbonaceous in upper part . .	9	0
Shale, grey micaceous; beds (up to 2 in thick) of fine-grained slightly calcareous sandstone . .	5	0
Shale, *poorly exposed* . . about	5	0
Sandstone, grey (brown-weathering) fine-grained slightly calcareous; plant fragments and fragmentary shell debris . .	4	0
Shale, grey, *poorly exposed* . .	4	0
Sandstone, fine-grained; irregular bedding; thin shale partings	12	0
Coal		2
Mudstone, rooty, on grey shale; *poorly exposed*	8	0
Sandstone, grey (brown-weathering) fine-grained	2	0
Shale, grey; some beds of sandstone; *only partially exposed* about	30	0
Sandstone, grey (brown-weathering) thinly-bedded and false-bedded medium-grained; plant fragments; slightly calcareous at some levels . .	10	0
Not exposed . . . . about	15	0
BINKY LINN LIMESTONE		
Limestone, grey argillaceous; algal	2	0
Shale, black	1	6
Sandstone, massive false-bedded fine-grained [6607 8414] . .	25	0

LEWIS BURN CATCHMENT

Marven's Cleugh. About 900 ft of strata are exposed discontinuously in Marven's Cleugh [5783 8657 and 5766 8624 downstream to 5853 8623] where they dip south-eastwards at 15° to 30°. They are mostly sandstones, generally fine-grained and greenish in colour, partly massive and partly thinly-bedded. Partings of greenish grey to purple mudstone and argillaceous sandstone are numerous; some are as much as 40 ft thick (for petrography see p. 214).

Similar strata are exposed in Little Marven's Cleugh [between 5858 8674 and 5872 8638] and in Drowned Sike [5889 8653].

Stony Sike. Flaggy, argillaceous, greenish sandstone is exposed [5935 8700] at the head of Stony Sike. Higher strata are seen intermittently downstream: they include the following sequence measured between 180 and 300 yd upstream of the confluence with the Lewis Burn [5957 8649 to 5953 8662]:

	ft	in
Shale, blue silty; becoming grey and finer-grained below	2	0
Coal		½
Clay, brown		6
Mudstone, greenish silty; rootlets	1	0
Sandstone, fine-grained ferruginous	1	0
Sandstone, argillaceous fine-grained; greenish in upper part brown in lower part with some coarser, thinly-bedded partings	13	0

Lishaw Burn and Yett Burn. The lowest 1000 ft of the Middle Border Group in this area consist largely of sandstone, forming a wide outcrop with a gentle south-easterly dip. Many small exposures on Long Rigg and Lishaw Rigg show the sandstone to be massive, fine-grained and quartzitic. A typical section, by the roadside [6099 8633] 150 yd S.S.E. of High Long House, is as follows:

	ft
Sandstone, thin-bedded fine-grained	4
Shale, blue-grey	3
Sandstone, flaggy fine-grained, argillaceous at top	4
Sandstone, massive fine-grained	6

The highest sandstone is slightly metamorphosed in contact with Lewis Burn–Troughend Dyke (pp. 242–8). A rock-gorge at the waterfalls [614 863], 500 yd E.S.E of High Long House, is cut through 50 ft. of partly massive and partly false-bedded, fine-grained sandstone (for petrography see p. 214).

Numerous disconnected exposures of fine-grained sandstones, varying from massive to flaggy, and generally strongly false-bedded, are present in Lishaw Burn. In places the sandstones are somewhat argillaceous with a greenish tinge. A 4-in unfossiliferous argillaceous limestone overlies a 1-ft sandstone with calcareous nodules [5969 8453], 1½ miles S.S.W. of High Long House. Farther upstream, a north–south anticline [5957 8423] and syncline [5952 8420] cross the burn, and an exposure on the west limb of the syncline illustrates the lithology of a more argillaceous part of the sequence:

	ft
Mudstone, greenish	1
Sandstone, thinly-bedded fine- to medium-grained	3
Sandstone, argillaceous soft green fine-grained; partly thin-bedded	2½
Mudstone, green thinly-bedded silty	3
Sandstone, fine-grained massive	1
Shale, grey-brown	5
Conglomerate, with pebbles of mostly rounded limestones up to 1 in across, in a matrix of medium-grained white sandstone	½
Sandstone, soft massive argillaceous	6
Shale, grey	3

Near Will's Knowe, on the left bank of Yett Burn [6118 8501], a small north-westerly fault is flanked on the north-eastern, upthrow side by massive, fine-grained sandstone (for petrography see p. 214), and on the downthrow side by the following section:

	ft
Sandstone, flaggy brown and green; silty shale partings	8
Mudstone, mottled purple and green, silty; green and sandy at base	8
Sandstone, fawn fine-grained massive; poorly cemented except at top	11
Mudstone, grey-green and buff, soft; very silty, with sandy shaly partings	12
Sandstone, fine-grained siliceous; specks of limonite	7
Shale, grey-green	1½
Sandstone, bronw and green soft argillaceous	5

	ft
Sandstone, massive, fine-grained, siliceous	8
Sandstone, blue-grey shaly fine-grained; carbonaceous fragments	2

Green and purple mudstones and argillaceous sandstones are exposed in Black Sike [near 6075 8420] close to the Beckhead–Binky Linn Fault.

Burnt Tom to Broomylinn. The high ground north of Broomylinn [6314 8438] culminating in Muckle Knowe [621 860] and Rough Pike [628 861] is formed by 300 ft of strata, almost entirely sandstones, dipping gently eastwards. Exposures are few. The west-facing escarpments of Muckle Knowe show crags of massive false-bedded fine-grained sandstone. About 20 ft of false-bedded sandstone with some irregularly contorted bedding are exposed in Gill Sike [6229 8443], about half a mile W. of Broomylinn. In the upper part of Short Cleugh [628 870], near the Lewis Burn–Troughend Dyke, nearly 100 ft of approximately horizontal, massive, fine- to medium-grained sandstones are exposed.

D.H.L.

References

Anderson, F. W., 1950. Some reef-building calcareous algae from the Carboniferous rocks of northern England and southern Scotland. *Proc. Yorks. geol. Soc.*, **28,** 5–28.

Craig, G. Y. 1956. The Lower Carboniferous outlier of Kirkbean, Kirkcudbrightshire. *Trans. geol. Soc. Glasg.*, **22,** 113–32.

Fowler, A. 1966. The stratigraphy of the North Tyne basin around Kielder and Falstone, Northumberland. *Bull. geol. Surv. Gt Br.*, No. 24, 57–104.

Garwood, E. J. 1931. The Tuedian Beds of northern Cumberland and Roxburghshire, east of the Liddel Water. *Q. Jl geol. Soc. Lond.*, **87,** 97–159.

George, T. N. 1958. Lower Carboniferous palaeogeography of the British Isles. *Proc. Yorks. geol. Soc.*, **31,** 227–318.

Lumsden, G. I. and Wilson, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

McKee, E. D., Reynolds, M.A. and Baker, C. H. 1962. Laboratory studies on deformation in unconsolidated sediment. *Prof. Pap. U.S. geol. Surv.*, 450-D, D151–D155.

Miller, H. 1887. The geology of the country around Otterburn and Elsdon. *Mem. geol. Surv. Gt Br.*

Nairn, A. E. M. 1956. The Lower Carboniferous rocks between the River Esk and Annan, Dumfriesshire. *Trans. geol. Soc. Glasg.*, **22,** 80–93.

Peach, B. N. and Horne, J. 1903. The Canonbie Coalfield: its geological structure and relations to the Carboniferous rocks of the north of England and central Scotland. *Trans. R. Soc. Edinb.*, **40,** 835–77.

Prentice, J. E. 1960. Flow structures in sedimentary rocks. *J. Geol.*, **68,** 217–24.

Robson, D. A. 1956. A sedimentary study of the Fell Sandstones of the Coquet valley, Northumberland. *Q. Jl geol. Soc. Lond.*, **112,** 241–58.

Trotter, F. M. and Hollingworth, S.E . 1932. The geology of the Brampton district. *Mem. Geol. Surv. Gt Br.*

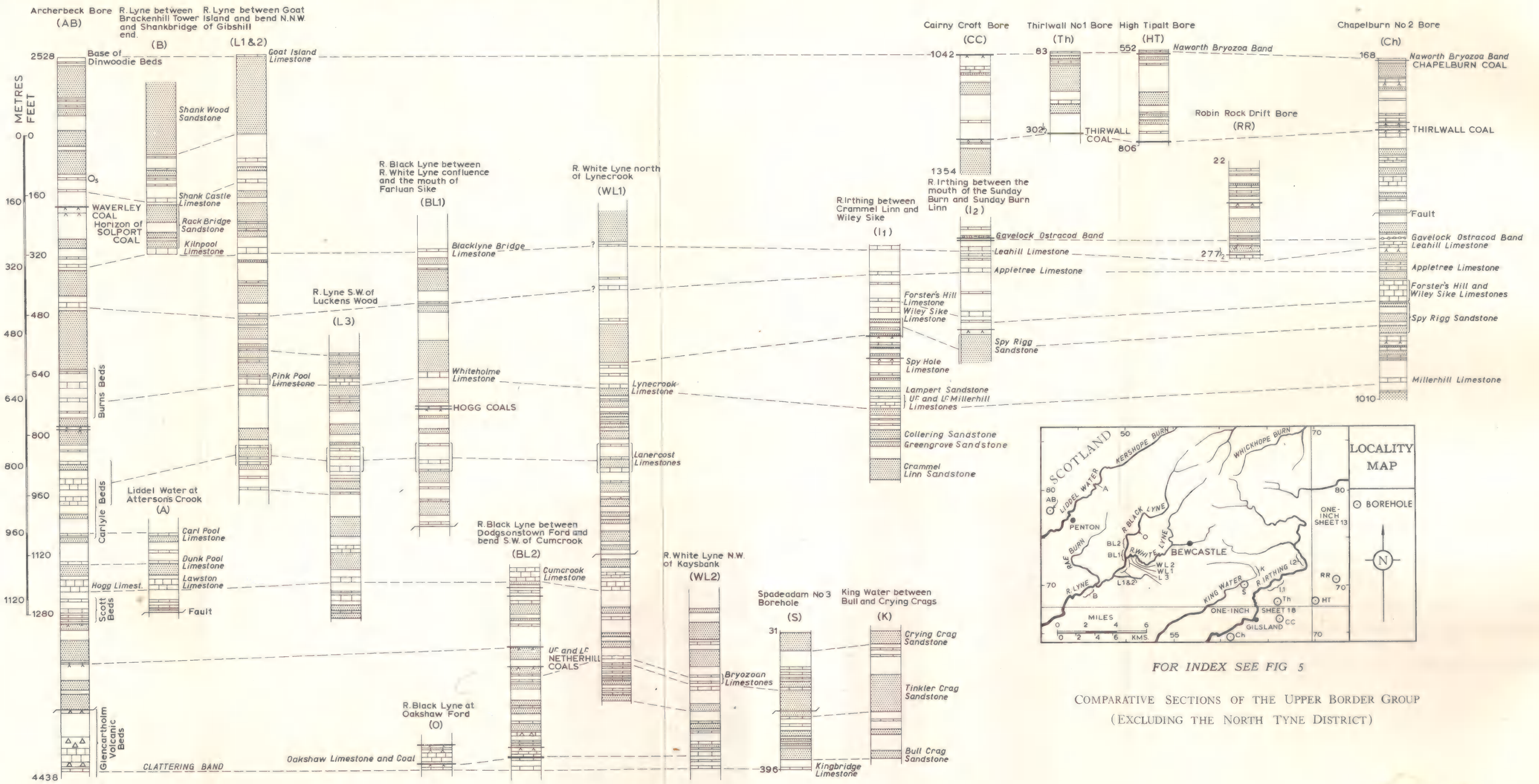
ıse
of
nd

ɔal
re-
8)
ıill
on
he
tle
he
ɔld
he
ter
ɔw
ıes
ɔle
.

ms
ıly
he
ırt
od
to
wn
gy
ırs
ver
he
ep-
ive
nd
he
cal
he
ed
a
ng

Geology of the Country around Bewcastle *(Mem. Geol. Surv.)*

PLATE V



FOR INDEX SEE FIG 5

COMPARATIVE SECTIONS OF THE UPPER BORDER GROUP
(EXCLUDING THE NORTH TYNE DISTRICT)

M.M.P Ltd. Dd 147220-4957

Chapter V

UPPER BORDER GROUP

General Account

The Upper Border Group is here defined as extending upwards from the base of the Clattering Band, or the equivalent Kingbridge Limestone, to the base of the Dinwoodie Beds, or the equivalent Naworth Bryozoa Band and Goat Island Limestone. The succession is shown in graphic form in Pl. V[1] and Fig. 26.

The group is equivalent to most of the Carbonaceous or Scremerston Coal Group, the name given by Tate (1867) in north Northumberland to the predominantly non-marine beds between the ill-defined top of the Tuedian (p. 8) and the base of the Dun Limestone. It also approximates to the Craighill Sandstone Group and overlying Birdoswald Limestone Group of the Brampton (18) district to the south (Trotter and Hollingworth 1932, pp. 29–43). The Brampton nomenclature, however, appears to be inappropriate to the Bewcastle district where the sequences displayed in the River White Lyne and by the Archerbeck and Spadeadam No. 3 bores show no justification for a twofold subdivision on lithological grounds. Moreover, the original description of the Craighill Sandstone Group was based on the correlation of the Kingwater Beds with a section in the River Lyne near Brackenhill Tower which is now known to lie nearly 1300 ft higher in the succession. The Kingwater Limestones sequence as described by Trotter and Hollingworth has also proved unreliable (p. 84), so that it has become necessary to rename the individual limestones.

The selection of a lower limit for the Upper Border Group has posed problems which are still not wholly resolved. In the central part of the sheet a thin, highly fossiliferous shale—here called the Clattering Band—lying a few feet below the coal and limestone at Oakshaw Ford, has been a natural choice; it forms part of a long measured section and its fauna has been described by Garwood (1931, p. 124), who suggested a correlation with the Kingwater Beds farther to the south-east. Re-examination of the respective faunas, however, has shown that very few forms are common to both localities; furthermore, the lithology of the Kingwater Beds, distinctive throughout three miles of strike section, bears little resemblance to the Clattering Band which is easily identifiable in the River White Lyne 1¾ miles S.S.W. of Oakshaw Ford and near the bottom of the Archerbeck Bore 6 miles to the west-north-west. Nevertheless, with one exception (p. 92) the Kingbridge Limestone and the Clattering Band in their respective areas mark the lowest appearance of *Lithostrotion martini* Milne Edwards and Haime, and directly overlie the highest of the algal limestones which typify the Lower and Middle Border Groups. In addition, both horizons lie within the local range of *Dyscritella nana* Lee, a species with a vertical range of only 500 ft in the Archerbeck Bore. For these reasons the Clattering Band is tentatively equated with the Kingbridge Limestone and it must be supposed that the lack of a common diagnostic fauna reflects a change in lithology in the six miles separating the White Lyne and King Water exposures. In the north-eastern part of the district the Clattering Band cannot be identified and the mapping of the base of the Upper Border Group is based mainly on lithology.

---

[1] Numbers in metre scale on Plate V should be divided by 3.

The base of the Dinwoodie Beds is taken as the upper limit of the groud because it marks the entry in the Archerbeck Bore of such D_1 species as *L. junceum* (Lumsden and Wilson 1961). The beds are firmly correlated with the Bryozoa Band about 70 ft below the Naworth Limestone of the Brampton succession. Although this Naworth Bryozoa Band is not exposed in the Bewcastle district and the crop shown on the one-inch map is conjectural, its position in the sequence is known from sections in Castle Beck and in the Cairny Croft Borehole farther south (Trotter and Hollingworth 1932, pp. 38–9, 200).

In the central part of the Bewcastle district the Dinwoodie Beds are thought to be represented by the Goat Island Limestone which contains abundant *L. junceum* in its roof and occurs at the top of a long, almost unbroken Upper Border Group sequence in the River Lyne. Higher beds are not exposed and the remainder of the Dinwoodie fauna has not been found.

Because exposure above and below the Lanercost Limestone is poor at the type locality in the Brampton district (Trotter and Hollingworth 1932, p. 38) and because three limestones occur at about the same position in the Bewcastle district, precise correlation is uncertain. The three limestones are therefore collectively referred to as the Lanercost Limestones in this memoir: the two lowest are equated with thick limestones near the top of the Carlyle Beds of the Archerbeck Bore (Pl. V). It is similarly difficult to identify the Millerhill Limestone, defined by Trotter and Hollingworth (1932, p. 35) as the 'principal of four shallow-water limestones' occurring above the Lanercost Limestone. The old quarries at Millerhill, like those at Bankhouses (p. 157) cannot be related accurately to a measured section. In the Gilsland Gorge (Fig. 22) two limestones —the lower of which appears to be the Millerhill of Trotter and Hollingworth— are here called the Lower and Upper Millerhill Limestones; they can be traced through the Lower Irthing catchment into the Spy Rigg section of the Upper Irthing (Fig. 23), despite variation in their thickness and lithology.

Lithology. In central, southern and western parts of the district Upper Border Group strata are dominantly marine and are similar to the beds of the underlying group except that rock-forming algae are insignificant. Thick, massive limestones such as those at Oakshaw Ford or Lawston Linn are rare and dolomitization is uncommon. Thin detrital limestones are common and are grouped together in sequences of fossiliferous, calcareous shale. Sandstones are still the thickest members of each cycle. Coals underlain by seatearths occur throughout the sequence, but in contrast with the seams of the approximately equivalent Scremerston Group in Northumberland few are thick enough to have been worked. They include, however, the Oakshaw Seam, up to 2 ft thick, which has been worked around the edges of the Oakshaw Ford Coal Basin, and an 18- to 24-in seam below the Lawston Limestone higher in the sequence (Lumsden and Wilson 1961, p. 5). Near the top of the group in the south-east corner of the sheet the Thirlwall Coal, up to 3½ ft thick, was mined extensively until 1926 and some reserves in this seam still remain. J.B.W.D.

In the north-eastern part of the district the lithology is transitional between the dominantly marine sequence to the south and west and the generally 'non-marine', carbonaceous sequence of the Scremerston Coal Group farther north-east (Miller 1887, pp. 20–41; Fowler 1936, pp. 17–21; 1966, pp. 71–94).

The sequence is a cyclic one, each cycle being generally between 10 and 50 ft thick and consisting of:

4 Coal (not always present)
3 Strata with rootlets
2 Strata, unfossiliferous
1 Strata with marine fossils

Items 1, 2 and 3 vary in grade from fine shale or mudstone to medium-grained sandstone, and no constant or even general sequence of rock types (in terms of grade) can be recognized. Rootlets or marine fossils are as likely to occur in sandstone as in mudstone. It seems likely, therefore, that the sequence represents an interdigitation of marine items (1) with non-marine items (2 to 4). Marine strata make up about 10 per cent of the whole sequence. While the majority of these have only a low carbonate content, argillaceous or arenaceous limestones are not uncommon. Only about twenty of the limestones, however, exceed 6 inches in thickness; the 7-ft Whickhope Linn Limestone, for example, is unusually thick for this part of the district. Corals are known from only six of the limestones.

The coals or coaly beds at the tops of cycles are generally thin; and in places they are represented merely by carbonaceous shales. About a dozen seams attain sufficient thickness to have been worked locally from adits at outcrop. The Shilburnhaugh Coal, in the north-east of the district, was more widely worked and had a good reputation as a house coal. In the adjoining Kielder Castle (7) and Elsdon (8) districts to the north and north-east, the Plashetts Coal attains a thickness of 3½ to 4½ ft and has been extensively worked (Fowler 1966). Its outcrop just enters the Bewcastle district near Burnt Tom [626 871].

Sandstones comprise about 30 per cent of the total sequence. Both laterally and vertically they are remarkably uniform (see p. 208), being typically pale grey with a slight purple tinge, evenly graded, medium-grained, cross-bedded, poorly cemented, quartzose and practically feldspar-free. Individual sandstones, rarely more than 30 ft thick, are either thin-bedded or thick-bedded. Irregularly contorted bedding, common in the Middle Border Group, has been noted in a few sandstones low in the Upper Border Group. Because of faulting few beds can be traced laterally for more than two miles, but some of the sandstones can be seen in places to die out abruptly.

Chert has been seen at only one locality, Low Cranecleugh [6618 8557], where a 9-in bed of black chert lies between beds of calcareous siltstone.

D.H.L., D.A.C.M.

Contemporaneous volcanic rocks. The sequence at Oakshaw Ford includes at the top of the Oakshaw Limestone a thin bed of volcanic tuff (Smith 1912, p. 155; Garwood 1931, p. 124). From its position in the sequence there is little doubt that this is the attenuated representative of the Glencartholm Volcanic Beds of the River Esk, and almost certainly derived from the same source, though only one vent has been found on the English side of the border. The distribution of the tuff is limited, for it is absent at the same horizon in the Black Lyne, only 1¼ miles S.W. of Oakshaw Ford, although a tuffaceous limestone is present at a slightly higher level; nor is there any trace of tuff in the Oakshaw Limestone in the River White Lyne to the south.

No contemporaneous igneous rocks are known in the north-eastern part of the district. J.B.W.D., D.H.L., D.A.C.M.

Thickness. A complete and virtually uninterrupted sequence of the Upper Border Group is known only from the Archerbeck Borehole where the group as now defined was encountered between 2528 ft and 4438 ft (Lumsden and Wilson 1961); the throw of a fault in the bore at 4272 ft is believed to be negligible. This thickness of 1910 ft compares with an estimated thickness for the group in the lower Irthing area, 15 miles to the south-south-west, of 2120 ft, but it is calculated to be thicker farther north in the North Tyne catchment.

J.B.W.D.

This calculation of greater thickness has not been founded on any continuous section through the group in the north-eastern part of the district, for none is available: on the contrary, sections through more than 100 ft of strata are rare, and faunas and lithologies are repeated both cyclically and by faulting. A composite section has therefore been made by measuring local sequences within each fault block and correlating them. The framework of the correlation is shown in Fig. 26 where certain sandstones are distinguished by numbers, though the diagram does not imply lateral persistence of individual beds. Where adjacent fault blocks have no recognizable strata in common the minimum possible displacement has been assumed for the intervening fault, thereby reducing the cumulative thickness to a minimum.

Three distinct sequences can be recognized. The lowest, comprising some 2000 ft of strata at the base of the group, lies south-west of the Blackcleugh Burn Fault. The highest sequence is about 1700 ft thick and crops out in the north-east corner of the district. It can be related to the Scremerston Coal Group of Tynedale (Miller 1887, pp. 29–41; Clough 1889, pp. 56–9; Fowler 1966, pp. 71–94) by mapping the Plashetts Coal, cropping out just beyond the margins of the district, and the Shilburnhaugh Coal 600 ft lower (see Fig. 27). A further sequence of about 2000 ft of strata (cropping out between the Blackcleugh Burn Fault and the eastern margin of the district) cannot be correlated with either of the other sequences, and is placed between them on structural grounds. Thus the thickness of measures between the base of the group and the Plashetts Coal is estimated to amount to some 5600 ft, implying that the original total thickness of the group before erosion may have been more like 6000 ft. Still farther north in the Lewis Burn area, the measures equivalent to the group are reduced to about 4000 ft or less (Fowler 1966). The area of greatest thickness seems to lie between the east–west Antonstown and Harrett's Linn faults, and it seems possible that these fractures may correspond, approximately, with sedimentary hinge-lines which were operative in Upper Border Group times.

D.H.L., D.A.C.M.

Distribution. Along the Scottish Border isolated exposures are present in the Kershope Burn from Kershope Bridge [501 834] upstream as far as the northern boundary of the sheet. In the Liddel Water near Atterson's Crook [463 812] the group is represented by the Lawston Limestone and associated beds. Lumsden and Wilson (op. cit., p. 5) were unable to correlate these beds, but reappraisal of their fauna and comparison of the measured section with the sequence between 3800 and 4000 ft in the Archerbeck Borehole suggest a correlation with the Hogg Limestone of the borehole and with the Cumcrook Limestone of the Bewcastle district (Pl. V).

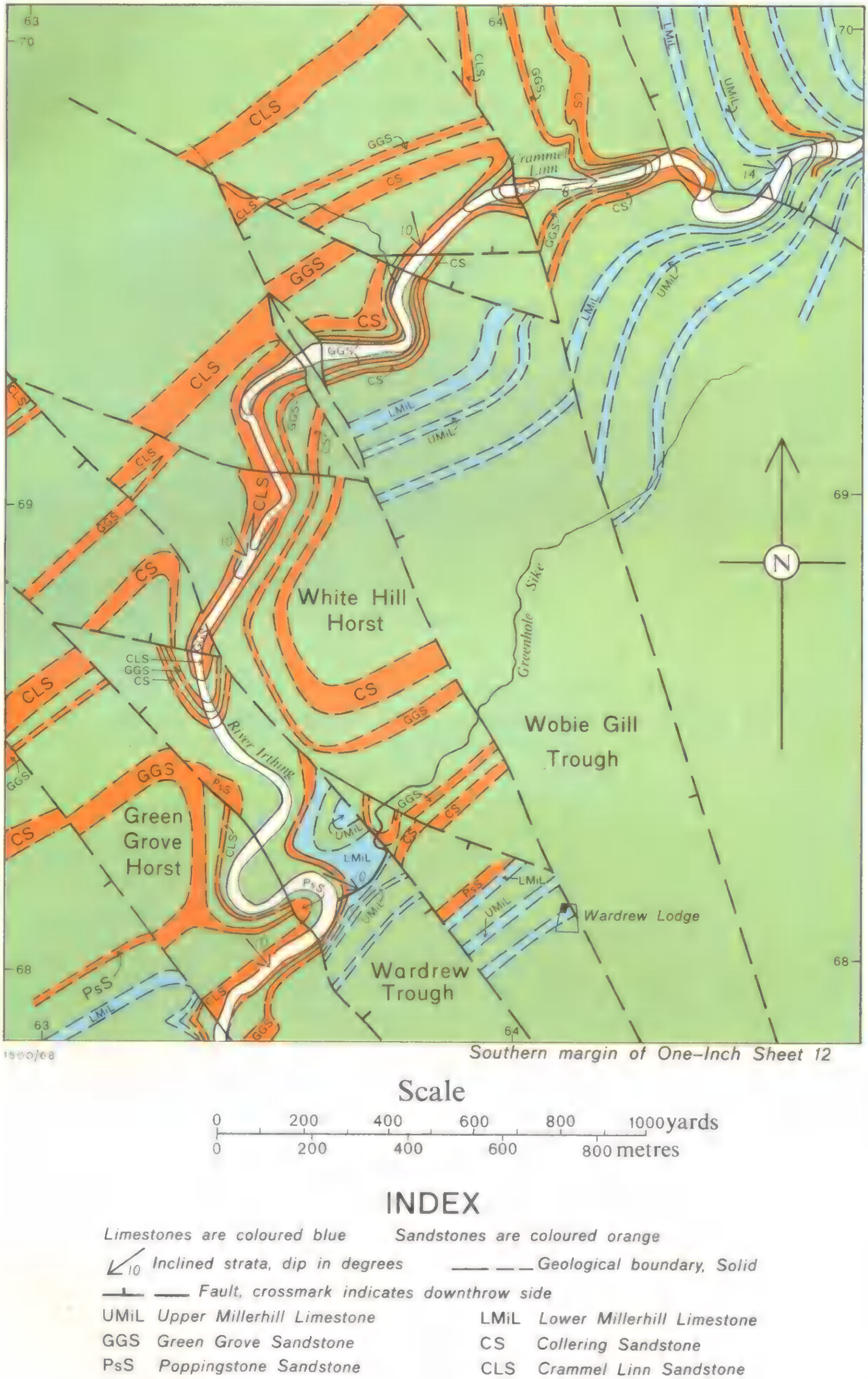

63
70
64
70
69
69
68
68
63
64
CLS
GGS
CS
LMiL
UMiL
Crammel Linn
14
8
10
15
11
White Hill Horst
Wobie Gill Trough
Green Grove Horst
Wardrew Trough
River Irthing
Greenhole Sike
Wardrew Lodge
PsS
N
1500/68
Southern margin of One-Inch Sheet 12
Scale
0 200 400 600 800 1000 yards
0 200 400 600 800 metres
INDEX
Limestones are coloured blue
Sandstones are coloured orange
10 Inclined strata, dip in degrees
Geological boundary, Solid
Fault, crossmark indicates downthrow side
UMiL Upper Millerhill Limestone
LMiL Lower Millerhill Limestone
GGS Green Grove Sandstone
CS Collering Sandstone
PsS Poppingstone Sandstone
CLS Crammel Linn Sandstone

FIG. 22. *Sketch–map illustrating the geology of Gilsland Gorge*

Most of the Lyne catchment is underlain by rocks of the group. Between Solport and the Back Burn Fault evidence from isolated exposures suggests much fracturing and folding, although detailed structural interpretation is not possible because of masking by drift. Between Southward Ford [452 697] and Shank Castle [460 704] the River Lyne has gouged a deep post-glacial gorge through the thick Shank Wood Sandstone which lies near the top of the group, and which is disposed in a shallow basin truncated to the north by the Pallyards Fault. Farther upstream, and to the east of the Goat Island–Lyne Thrust, a continuous exposure extends downwards between the Goat Island and Cumcrook limestones; the beds are reddened and nearly vertical. This section and another which extends in the River White Lyne from a horizon at or near the base of the Shank Wood Sandstone down to the Clattering Band, forms part of the steeply dipping faulted western limb of the Stapleton Anticline.

In the Black Lyne catchment, to the west of the Goat Island–Lyne Thrust, the beds from the Clattering Band up to the Cumcrook Limestone are disposed in a series of arcuate crops delineating the Oakshaw Coal Basin, bounded to south-west and south-east by the Dappleymoor Fault and Goat Island–Lyne Thrust. South of the Dappleymoor Fault, southward-dipping, partly reddened measures extending up to the Blacklyne Bridge Limestone are exposed in the River Black Lyne.

Conjectural crops of the group have been drawn on structural grounds in drift-covered ground north-west of Kirkcambeck between the Kaysbank and Low Park faults.

In the eastern part of the district, Upper Border Group rocks form part of the gently dipping eastern limb of the Bewcastle Anticline. In the south-east around Spadeadam, these rocks are mainly blanketed by drift, though moderately well-exposed sections in the lower beds of the group can be seen in the King Water, and a succession extending from a horizon below the Millerhill Limestones to one above the Leahill Limestone is well displayed in the River Irthing from the southern edge of the district as far north as Shankend [6877 7654]. The alternating troughs and horsts of the Gilsland Fault-belt are shown in Fig. 22.

North-east of the Gilsland Gorge the sequence includes a bed of calcareous shale or shaly limestone yielding abundant *Naiadites crassus*, believed by Garwood (1931, pp. 121–2) to occur at several levels. Locally, however, the species is abundant at only one horizon, here called the Irthing Shell-bed. This bed is particularly well developed in the strike-sections between Shank End and Lampert, and has proved to be a useful marker. The shell-bed is overlain by a thick and massive sandstone, which rises to 1027 ft A.O.D. on Spy Rigg, and which can be traced for some distance northwards towards Chirdon Burn.

Along the topographic divide between the Cumberland rivers and the River North Tyne many of the crags, including those of Christianbury (1598 ft O.D.) and Sighty (1702 ft O.D.), are formed from thick sandstones near the base of the group. Their outcrops are repeatedly displaced by a series of sub-parallel north-easterly faults, among them the *en échelon* extension of the Hole of Lyne Fault.

J.B.W.D.

In the North Tyne catchment, the lower beds of the group are exposed in the Yett and Back burns catchments. The position of the base of the group is based on lithology in this area as there is no faunal evidence. Upper Border Group rocks are grey, algae are sparse, coals (mostly very thin) are numerous, and irregularly contorted sandstone bedding is rare; by contrast, Middle Border Group mudstones and sandstones show greenish and purplish tinges, algae are present, coals virtually absent and irregularly contorted sandstone bedding common. Thick sandstones occur between 1000 and 1500 ft above the base of the Upper Border Group, and form the high ground around Gill Pike and Black Knowe. Discontinuous sections occur in Yett, Back and Gair burns. On Paddaburn Moor, south of the Antonstown Fault, exposures are almost confined to sandstone scarps facing south-west.

Strata in the upper part of the group are exposed in the Whickhope and Little Whickhope burns and in Clock's Cleugh and Chirdon Burn near Seven Linns. These sections suggest the correlation of Chirdon Nos. 1 and 2 coals with the Merlin Island and Merlin Crags coals, and the Chirdon No. 2 Limestone with the Jock's Pool Limestone. D.H.L., D.A.C.M.

DETAILS

KERSHOPE BURN CATCHMENT

Between the Kershope and Wythes faults. Upper Border Group rocks crop out in a belt about half a mile wide between the Kershope and Wythes faults and are terminated southwards by the Bailey Hope Fault. The regional dip is towards the east, but there are so many minor faults that no single composite section can be constructed.

The measures consist of sandstones, shales and thin limestones, with a few thin coals. Within the limestones and calcareous shales bivalves and ostracods are common, bryozoa and gastropods less so. The most northerly exposure, at Corby Linn [5557 8733], consists of 30 ft of light brown, well-graded, current-bedded sandstone. Several thin limestones, one containing chert, can be seen in the lowest 200 yd of Riding Grain, where the dips vary greatly both in amount and direction (loc. 57); one reading of 65° to north-west [5555 8305] may be inverted. In the left bank of the Kershope Burn [5542 8690] the following section is exposed:

	ft
Sandstone, rubbly	3
Shale, banded	1
Coal	¾
Fireclay	1
Shale, rooty	1

Good sections are visible in the lower reaches of Upper and Nether Castle cleughs, west of a branch of the Wythes Fault. The sandstone forming Little Dove Crag in Upper Castle Cleugh can be mapped along the strike to Nether Castle Cleugh. The following is the section in Upper Castle Cleugh, below Little Dove Crag:

	ft
Sandstone, brown medium-grained; worm markings [5548 8664] ..	3
Sandstone, calcareous; irony concretions; crinoids and bivalves ..	1½
Not exposed	4
Sandstone, brownish grey; plants	1½
Sandstone, fossiliferous calcareous	2
Shale, rubbly sandy	¼
Shale, soft; plants	¼
Coal and carbonaceous shale ..	¼
Shale, grey sandy; roots	1
Shale, calcareous hard; roots; ostracods	¼
Limestone, fine-grained grey nodular; few ostracods	¾
Not exposed	5
Sandstone, medium-grained; plant debris; shaly at base	6
Not exposed, apart from sporadic grey sandy shales	10
Shale, blue-grey; sandstone partings	?
Not exposed; thickness uncertain..	?
Sandstone, grey-brown medium-grained current-bedded [5544 8665]	15
Shale, brown sandy	¾
Shale, grey; plants at base ..	1½
Sandstone, green-grey; roots ..	½
Not exposed; shale debris.. ..	12
Sandstone, medium-grained; plants	2

	ft
Shale, grey	1
Sandstone, light grey medium-grained slightly calcareous; brachiopods, bivalves and bryozoa ..	12
Not exposed; thickness uncertain	?
Shale, dark grey; ostracods [5541 8667]	6
Sandstone, very hard light grey medium-grained	1⅓
Not exposed; grey shale debris ..	8
Sandstone, light grey slightly calcareous; crinoidal, with worm markings	6
Not exposed; thickness uncertain	?
Coal [5532 8671] 7 in	½
Shale, dark; coal partings ..	2

Sections of similar lithology in Nether Castle Cleugh extend downwards from above the horizon of the Little Dove Crag Sandstone and include at least two thin coals and several thin ostracodal limestones.

Approximately equivalent beds exposed intermittently in Black Cleugh consist mainly of sandstones and shales, with limestones upwards of 3 ft thick containing brachiopod fragments and a thin coal [5505 8615]. Farther upstream the following can be seen:

	ft
Limestone, grey crystalline; brachiopod fragments and ostracods; partly decalcified [5499 8598] ..	1
Shale parting	¼
Limestone, grey crystalline weathering to rottenstone; ostracods abundant	1
Shale, grey	1½
Sandstone, hard green—flexes gently	¼
Shale, grey	½
Sandstone, grey-green thin-bedded medium-grained	3
Not exposed	?
Shale, grey sandy [5500 8601] ..	1
Sandstone, brown and light grey blocky	1
Shale, dark grey sandy	1½
Shale, blue-grey soft	1¼
?Small fault, downthrowing north	?
Shale, grey nodular sandy; rusty-weathering	2
Not exposed	6
Sandstone, light grey medium-grained massive	2
Not exposed	?
Sandstone or sandy limestone, fine-grained brown-weathering calcareous; ostracods	2
Not exposed	?
Shale, dark grey	1¼
Shale, calcareous; worm-like markings	1¼
Shale, hard grey fossiliferous calcareous	1
Shale, grey	½
Not exposed	4
Shale, grey	½
Limestone, impure grey shaly; brachiopods, ostracods and bryozoa	2½
Not exposed	1½
Shale, grey sandy	½
Sandstone, grey shaly	½
Not exposed	4
Sandstone, hard grey	1
Not exposed	?
Limestone, blue-grey oolitic algal	2½
Not exposed	2
Limestone, fine brown-weathering; concentric structures	1
Not exposed	?
Sandstone, grey-green rubbly ..	3
Shale, grey sandy	1¼
Shale, blue-grey	⅓
Shale, grey	1½
Sandstone, grey-green	5
Not exposed	4
Sandstone, grey-green flaggy micaceous [5502 8605]	3

Exposures of sandstone, shales and a single thin limestone in Rowantree Sike probably lie lower in the succession than these beds in Black Cleugh.

Several thin, fine-grained limestones, with ostracods and shell debris, can be seen in the Kershope Burn, north of the Kershope Fault. One, which is at least 6 ft thick, passes down to cementstone at the base. Two others are upwards of 1 ft and 2 ft thick respectively. Still farther north a 4-ft limestone is overlain successively by 6 ft of sandstone and 2 ft or more of sandy limestone dipping eastwards at 40°.

Intermittent exposures, mainly of sandstone, occur in Craggy Cleugh east of the Kershope Fault. In the upper part of the cleugh southerly dips probably reflect the influence of the nearby Bailey Hope Fault.

North of the Kershope Fault. Rocks of Upper Border Group age crop out in a narrow belt of country between the Kershope Fault and the Border. Hillwash and boulder clay obscure much of the solid except in Craggy Cleugh and Golden Cleugh. In Craggy Cleugh [5308 8564], near its confluence with Kershope Burn, the following section is exposed:

	ft
Limestone, dark grey ?cherty ..	1
Coal, inferior; lenticular 1 to 2 in	—
Seatclay, grey	¾
Shale, grey; rootlets	2
Shale, grey-green soft; hard bands	1
Shale, black rusty-weathering hard rubbly	2½
Coal, inferior .. .. ½ in	—
Shale and seatclay, black carbonaceous; calcite partings	1¼
Coal .. .. .. 2 in	—
Seatclay, black	½
Not exposed	3
Shale, dark grey sandy; calcite veins	1¼
Shale, dark grey rubbly calcareous; worm-like markings and a few small brachiopods at top	3¾
Limestone, grey hard earthy; worm-like markings on brown weathered surfaces; shell debris includes *Myalina sp.*	3
Shale, calcareous; poorly preserved fossils	1½
Limestone, grey shaly	⅓
Not exposed	4 to 5
Sandstone, white hard fine-grained; finely current-bedded; rootlets at top	4½
Shale, grey	¾
Limestone, blue-grey crystalline; *Dyscritella?* and smooth-shelled bivalves (loc. 58)	½
Limestone, grey earthy	½

In the Kershope Burn, farther downstream (loc. 59), a prolific fauna has been obtained from several thin limestones which are associated with calcareous shales and interrupted by a small fault. Still farther downstream the following strata are folded into a small north–south anticline [5107 8425]:

	ft
Sandstone, medium- to coarse-grained; calcareous at base; plant debris	6
Shale, sandy rubbly; rootlets ..	1⅓
Limestone; shell debris	⅓
Shale, sandy banded; sandstone partings; *Modiolus sp.*	3
Limestone, grey earthy	1

Between the anticline and the mouth of Golden Cleugh there are several exposures of shale and sandstone.

Exposures in Golden Cleugh are interrupted by several faults of uncertain, but probably small, displacement which trend parallel to the Kershopefoot Fault. The following section was measured on the north side of the northernmost fault [5088 8411]:

	ft
Shale, dark grey; plants	6
Shale, dark grey rubbly sandy ..	2½
Shale, grey; plants..	⅓
Shale, grey calcareous; thin limestone bands; ostracods and gastropods at top; shelly beds with bivalves and brachiopods at base (loc. 60b)	2½

On the southern, downthrow, side of the fault are 7¾ ft of shales containing coaly films in the uppermost 6 ft and plant remains near the base.

The next fault upstream [5090 8406] brings together 4 ft of grey soft shale with thin ironstone bands on the northern side, against grey-black rubbly sandy micaceous shale on the southern, downthrow side. Still farther upstream a fault [5091 8402] with a northward downthrow separates horizontally-bedded, creamy brown, medium-grained sandstone on the northern side from 4 ft of crumpled and contorted alternating bands of sandy shale and flaggy sandstone which overlie shattered grey rooty sandstone dipping northwards into the fault. Only ten yards away, another fault [5092 8401], hading south at 45°, brings down 6 ft of dark grey sandy shale with ironstone bands against 2 ft of contorted calcareous shale with productids and bivalves.

In a small tributary [5092 8396] to Golden Cleugh, shaly coal 9 in thick is exposed. It is underlain by grey seatclay and is succeeded by 2 ft of black carbonaceous shale which gives way in upward succession to 9 ft of grey sandy shale with ironstone bands.

Farther east [5101 8394], in Golden Cleugh, are 14½ ft of shales, which are rooty at the base, carbonaceous and sandy in the middle and fossiliferous in the uppermost 8 ft. Farther upstream [5106 8390] unfossiliferous shales and sandstone overlie nearly 6 ft of shales with ironstone nodules and with abundant shelly brachiopods and large *Lingula sp.* in the topmost 15 in. Still farther upstream [5109 8388] 2½ ft of fine grey crinoidal limestone with brachiopods rest on at least 1 ft of calcareous shale with thin limestone bands, brachiopods and corals. It is separated by an uncertain thickness of measures, including sandstone, from another limestone which crops out in the following section (loc. 60a):

	ft
Shale, dark grey; rare brachiopods	2
Shale, calcareous; brachiopods ..	½
Limestone, dark earthy fossiliferous	½
Shale, calcareous; earthy limestone partings	1¼
Shale, grey; nodular at top ..	—

The fauna from this section includes *Semiplanus sp. nov.* and cf. *Stenoscisma isorhyncha*—species indicative of the lower part of the Upper Border Group.

South of the Kershopefoot Fault. Upper Border Group rocks crop out along the higher, southern slopes of the valley of the Kershope Burn south of the Kershopefoot Fault and south of Kershope Bridge and Kershopefoot village. Dense forest masks much of the ground and the only section of importance is in Thief Cleugh, though isolated exposures also occur in parallel streamlets. The Thief Cleugh section consists chiefly of thin limestones alternating with calcareous shales and subordinate sandstones. There are also trial workings for coal at two horizons, but the only seam seen is 6 in thick; it crops out in a tributary to the east of Thief Cleugh [4939 8243]. Fossils collected from the cleugh (locs. 61a, 61b) include such typical Upper Border Group forms as *Naiadites crassus* (Fleming), *Lithostrotion martini* Milne Edwards and Haime and *Semiplanus sp. nov.*

J.B.W.D.

LIDDEL CATCHMENT

Upper Border Group rocks are exposed in the Liddel Water (Pl. V) between Crowwood Pool and Pudding Crook, and in the tributaries Kiln Sike, Bent Sike, Long Cleugh, Caldwell Sike and Kitchen Sike. They are represented mainly by massive limestones in association with calcareous shales. Sandstones, seatearths and thin coals are rare. The limestones and shales contain an abundant and diversified fauna, among which brachiopods and corals are common.

Liddel Water. The lowest section exposed in the Liddel Water includes the Lawston Limestone, which crops out in the right bank at Attersons Crook [4640 8097] as follows:

	ft
Sandstone, fine-grained	—
LAWSTON LIMESTONE	
Limestone; abundant productids, *Lithostrotion sp.* etc.	21
SCOTT BEDS (OF ARCHERBECK BOREHOLE)	
Shale, calcareous sandy; sandstone bands; rare shells	20
Limestone, earthy fossiliferous	2¼
Shale, fossiliferous	8
Limestone, shaly impure; shale partings; *Lithostrotion sp.*, productids and bryozoa	4
Shale, calcareous; *Lithostrotion sp.*	3¾
Limestone, earthy; large productids and *Lithostrotion sp.* ..	3
Shale, hard calcareous; *Lithostrotion sp.*, productids ..	4
Fault, small	?
Shale, sandy calcareous; shelly ..	4
Shales; a few shells	8

The limestone next in upwards sequence is exposed in the right bank of the river at Dunk Pool [4640 8074] from which it takes its name. The section lies north of an east–west fault and is as follows:

	ft
Sandstone	—
Shale, dark; ironstone nodules	12 to 15
DUNK POOL LIMESTONE	
Limestone, fine-grained hard blue-grey; rare brachiopods ..	6
Shale, grey calcareous; brachiopods	3

The Dunk Pool Limestone is also exposed in the river south of Pudding Crook (loc. 62a) where it comprises 3 ft of fine to coarse crystalline limestone closely folded against the northerly continuation of the Back Burn Fault. The overlying sandstones form a series of shallow waterfalls, and are traversed by an east-north-easterly dyke (p. 246) along the south side of a sharp bend in the river.

Between the two exposures of the Dunk Pool Limestone, and separated from them by faults, is an unnamed limestone [4628 8059] at least 2 ft thick. It is flexed into a gentle synclinal structure and is overlain on the left bank by up to 10 ft of rubbly, rooty, micaceous, partly calcareous sandstone. The limestone, which lies between the Dunk Pool and Carl Pool limestones, is here equated with a grey calcareous sandstone recorded in the Archerbeck Bore at 3855½ ft (Lumsden and Wilson 1961, p. 40).

The next limestone in upward succession is the lowest of those grouped as Carlyle Beds in the Archerbeck Bore (Pl. V). It is here named Carl Pool Limestone and is seen in the Liddel on the southern arm of Pudding Crook (loc. 62b) and at Fowlsnest and Rutty pools (locs. 62c, 62d). At the first locality it is at least 5 ft thick and is underlain by 5 ft of rooty sandstone with a shale bed; the lower half of the limestone is shaly and crinoidal and the upper half is a coarsely crystalline rock containing crinoids and brachiopods. At the other two localities the fauna is more varied and abundant.

Between Rutty Pool and the mouth of Long Cleugh [4728 8140] the Carlyle Beds are folded into a gentle syncline, and two further limestones are exposed. *Girvanella staminea* is recorded from the lower limestone. The higher crops out at the mouth of Long Cleugh (loc. 62e), where it contains *Chaetetes depressus* and *Semiplanus sp. nov*. Still higher measures are exposed in Long Cleugh: they include 2 ft of impure fossiliferous limestone [4775 8142] overlying rooty sandstones and shales.

Long Cleugh and adjacent tributaries of the Liddel Water. On the north bank of Long Cleugh, a few yards east of the roadbridge, 3 in of carbonaceous shale and coal are overlain by 33 ft of shales and calcareous shales with intercalated limestones up to 6 ft thick. Farther upstream, in Long Cleugh, the dip becomes westerly so that lower members of the Burns Beds are exposed: they include several thin fossiliferous limestones and calcareous shales (loc. 63).

	ft
Shale, grey sandy micaceous	1½
Sandstone, hard rooty	½
Sandstone, banded rubbly shaly; rootlets	8
Shaly, sandy; ironstone nodules; fossiliferous	2
Not exposed	about 5
Shale, black sandy; plant debris	1
Limestone, brown-weathering fine-grained grey; fossiliferous ..	6
Shale, dark grey sandy	2½
Limestone, grey earthy crinoidal; productids	1
Shale, dark calcareous; fossiliferous bands and nodules	5¼
Shale, blue-grey smooth; ironstone nodules; rare productids	2¼
Limestone, fine-grained grey; partly shaly; corals and brachiopods	1½
Shale, blue-grey smooth; very fossiliferous bands	3½
Limestone, dark grey earthy; shell debris	½
Shale, dark grey sandy micaceous; plant remains and rare carbonaceous partings (coal 3 in downstream)	8
Sandstone, light grey rooty ..	1
Shale and shaly sandstone in alternating bands	2½
Shale, dark grey sandy; rare shells	2½
Sandstone, brown calcareous ..	1¼
Sandstone, biscuit-coloured medium-grained flaggy; coalified plant debris	9
Sandstone, brown and light grey micaceous current-bedded; rare flaggy bands	5½

Further exposures of Burns Beds are seen to north and south in parallel streams such as Kitchen (loc. 64), Chickensfield, March (loc. 65) and Kiln sikes. One of the limestones, more than 6 ft thick, has been quarried in Chickensfield Sike (loc. 66) and has yielded *Chaetetes septosus*. The same limestone crops out in Kiln Sike, immediately east of Stonegarthside Farm, and 150 yd to south-east is another limestone [4755 8026] which is iron-rich, red and knobbly.

Leagair Quarry. At Leagair Quarry, half a mile south of Stonegarthside Farm, a limestone has been quarried for 400 yd along the strike. It is now mostly overgrown, apart from the following section (loc. 67):

	ft
Sandstone, rubbly grey	—
Shale, black; ironstone nodules; calcareous and fossiliferous at base	4

	ft
Limestone, blue flaky; fossiliferous	½
Limestone, massive fawn; rare shaly partings; fossiliferous ..	4

Since the dip is a little west of north at about 25°, it is evident that the limestone lies well below the Burns Beds cropping out in Kiln Sike: it is probably the Lawston Limestone.

Hagling Burn. In Hagling Burn, east of the Back Burn Fault, where there are old (circa 1840) trial workings for coal [4495 7596], the following section is exposed:

	ft
Coal, dull; occasional bright bands	1
Fireclay and shale, light grey ..	6
Shale, greenish sandy; a lens of sandstone; passing into ganister upstream	3
Mudstone, grey sandy	1¼
Fireclay, light grey sandy; wisps of coal at top	1½
Fireclay, dark shaly; abundant plant material	1

Farther upstream [4523 7600] there are traces of several old bell pits on both banks, but nothing is known of the seam to which they were sunk. Many limestone blocks occur at the head of the stream [4529 7595]. The measures here are grey, in contrast with those half a mile to south-west in the Back Burn, where there are several discontinuous exposures of reddened shales, marls and sandstones dipping into and away from the Back Burn Fault at about 45°.

J.B.W.D.

LYNE CATCHMENT

The Lyne Catchment is heavily drift-covered except along the main streams, where there are many fine continuous sections, particularly in the River Lyne.

River Lyne. East of the Goat Island–Lyne Thrust is a continuously exposed section consisting of about 1500 ft of nearly vertical strata extending from a horizon about 100 ft below the Cumcrook (Hogg) Limestone at Crabtree Pool [4970 7220] to the Goat Island Limestone at Goat Island [4859 7150]. The section (L1 and 2 of Pl. V) shows close lithological agreement with the relevant part of the Archerbeck Borehole. The lower part of the section, up to the Kiln Pool Limestone, is repeated in the river between Crabtree Pool and Luckens (L1 of Pl. V and Appendix I). The measures are deeply and uniformly reddened and have a nearly vertical disposition. In places the dip is inverted, but current-bedding in the sandstones indicates that the measures young uniformly to the west. These measures form part of a thrust-slice overlying the Goat Island–Lyne Thrust. Full details of the sections (L1, 2 and 3) are given in Appendix I (p. 302).

The lowest bed seen in the river [4972 7222] is a red sandy marl containing tiny turreted gastropods. It is succeeded by 85 ft of sandstones and shales, followed by a number of limestones including the red, crinoidal Cumcrook Limestone [4967 7228] which is more than 8 ft thick. Downstream from Crabtree Pool are three limestones [4948 7217], one of which is probably the correlative of the Lanercost Limestone of the Brampton district. At this locality limestones are 8, 4 and 8 ft thick, but the lowest is 15 ft thick in the reach 200 yd to N.E.

The Pink Pool Limestone lies 150 ft higher in the succession. At outcrop in Pink Pool [4938 7219] it consists of a lower 12-ft and an upper 5-ft leaf: the lower leaf is expanded to 18 ft about 400 yd to N.E. *Lithostrotion martini* and *L. portlocki* have been collected from this limestone (loc. 68a).

The 330 ft of strata between the Pink Pool and Kiln Pool limestones have an inverse dip of 60° to 70° to the east-south-east and consist mainly of sandstone with four thin limestones. The reddened Kiln Pool Limestone [4921 7210] is not completely exposed in this stretch of the river, where only 5 to 6 ft are visible. Higher beds crop out as far as the bend immediately east of Gibstown, the highest being the base of the Shank Wood Sandstone [4903 7204]. These measures between the Kiln Pool Limestone and the base of the Shank Wood Sandstone are also well exposed in the river on both sides of a suspension bridge [4897 7180]. The fossiliferous Kiln Pool Limestone (loc. 68b), varying in thickness from 15 to 18 ft, is traversed by a north-westerly dextral tear-fault which shifts its crop laterally about 20 ft. The crops of two higher 3-ft limestones cross the river on either side of the suspension bridge; the lower of these contains rare colonies of a cerioid *Lithostrotion* in addition to other fauna recorded from this locality (loc. 68e). The Shank Castle Limestone in this section is 7 ft thick with thin intercalations of red marl and with *Lithostrotion* colonies and bryozoa (loc. 68c).

The succeeding beds up to the base of the Shank Wood Sandstone consist mainly of marls with subordinate bands of sandstone, rarely calcareous, and a red limestone 9 ft thick. The marls above the limestone have yielded bivalves and small, tumid chonetids.

The base of the Shank Wood Sandstone crops out at the bend 130 yd W.N.W. of the suspension bridge, and the river follows the strike for more than 300 yd downstream. The sandstone is almost 200 ft thick and becomes progressively more massive towards the top. The 2½-ft Goat Island Limestone, somewhat higher in the sequence, is immediately overlain by 2 ft of shales containing masses of crushed *Lithostrotion junceum:* it can be seen in the overhanging left bank [4858 7150] a few yards upstream from Goat Island. This is the first appearance of *L. junceum*, and the Goat Island Limestone is therefore taken as the local base of the D_1 Subzone and correlated with the base of the Dinwoodie Beds of the Archerbeck Borehole and the Naworth Bryozoa Band of Brampton.

The Goat Island–Lyne Thrust crosses the eastern end of the island, and is manifested by a crush belt 30 yd wide in the left bank of the river. West of the fault the beds immediately above the Goat Island Limestone are sharply folded into two anticlines and one syncline. The core of the westernmost anticline is formed by the Goat Island Limestone which crops out in the river bed [4842 7145]. It is thus evident that the thrust has little throw at this locality. The Goat Island Limestone and the overlying *junceum* bed are again exposed along the strike downstream.

Between the Goat Island–Lyne Thrust and the Lynedale Fault trough, the Shank Wood Sandstone is continuously exposed and includes several thin red limestones with associated red marls. A narrow strip of Liddesdale Group strata is let down between the two Lynedale faults, but immediately to the west of them the Kiln Pool Limestone reappears in the left bank (loc. 46) where it consists of at least 8 ft of red crinoidal limestone with abundant colonies of *Lithostrotion martini* and *Syringopora sp.*

Between the Lynedale and Brackenhill faults the rocks are disposed in a broad basin in which beds extending from the Kiln Pool Limestone up to near the top of the Shank Wood Sandstone are exposed. The succession on the western side of the basin has been described by Trotter and Hollingworth (1932, pp. 30, 33, fig. 2) who correlated it with the Kingwater Beds at the top of the Middle Border Group. From re-identification of the fossils and comparison of measured sections it now appears that this correlation is erroneous and that the basal 'cementstone' of Trotter and Hollingworth is the Kiln Pool Limestone, 13½ ft thick, while their 'Productus Limestone' is the Shank Castle Limestone. These limestones are separated by the thick Rack Bridge Sandstone which contains rare calcareous bands presumed to represent two thin unnamed limestones in this part of the succession upstream. The Shank Castle Limestone is well exposed in the north bank (loc. 68f) 50 to 60 yd S.E. of Shank Castle where the section is

	ft
Sandstone, fine- to medium-grained pinkish	8
Marl, pale grey, red and purple ..	2
Not exposed	6
Limestone, grey red-stained; *Lithostrotion sp.*	2
Shale, reddish calcareous; *Lithostrotion sp.*	2
Limestone, grey red-stained sandy; fossiliferous	2 to 3
Marl, soft bright red and purple	2

Large, single corallites of *Palaeosmilia sp.* were also observed.

Higher strata are preserved between two faults crossing the river south-west of Shank Castle. They include a red crinoidal limestone, at least 1 ft thick and containing colonies of *Lithostrotion sp.* [4680 7015]. This bed probably represents one of the two thin red limestones exposed in the banks of the east limb of a horseshoe bend in the river, 500 yd S.W. of the castle. The succession, disturbed by a 3-ft north-north-westerly fault seen in the river bed near the mouth of the Rae Burn, is as follows:

	ft
SHANK WOOD SANDSTONE	
Sandstone, fossiliferous calcareous	1 to 2
Not exposed	30
Sandstone, red calcareous (at mouth of Rae Burn and affected by small fault)	1 to 2
Not exposed	11
Sandstone, massive current-bedded	9
Shale and marl, red	5
Limestone, impure fossiliferous red; abundant colonies of *Lithostrotion sp.*	1½
Sandstone, flaggy; thin shale band	16
Limestone, impure red	2
Shale and sandstone, red	—

The two calcareous sandstones of this section are again exposed near a sharp bend in the river, 800 yd S.W. of Shank Castle.

Between the bend and Southward Ford, three-quarters of a mile downstream, the river flows through a spectacular gorge, up to 70 ft deep, cut in the Shank Wood Sandstone. Just above the base of the sandstone is a 3-ft bed of conglomerate containing pebbles of deep purple marl in a matrix of medium-grained sand. The remainder of the sandstone has an unvarying pinkish red colour, from top to bottom. At Southward Ford, on the western limb of the broad syncline, the underlying limestones and calcareous sandstones are repeated. One of the fossiliferous calcareous sandstones is continuously exposed for several hundred yards in the right bank of the river between the ford and the next weir downstream. The Shank Castle Limestone is seen in the left bank [4471 6922], and underlying strata are continuously exposed as follows between this locality and the Brackenhill Fault at Kiln Pool:

	ft
Sandstone	—
Shale and marl	14
SHANK CASTLE LIMESTONE	
Limestone, red marly ..	1¾
Marl; *Lithostrotion sp.* and *Cyathophyllum sp.*	1⅔
Limestone; *Lithostrotion sp.*, *Syringopora sp.* and productids	3½
Marl, red	9
Sandstone, flaggy purplish ..	50
Sandstone, calcareous; fossiliferous	10
Marl, red striped; contorted ..	20
Sandstone	½
Marl, spotted red sandy; ?worm markings	4
Sandstone, purple flaggy; some marl	14
Sandstone, massive purple ..	4
Shale and marl, reddened sandy ..	6½
Sandstone, flaggy; subordinate marl bands	9
Sandstone, slightly flaggy purple ..	11½
KILN POOL LIMESTONE	
Limestone, hard red sandy; bands of crystalline limestone ..	4
Not exposed	1
Limestone, hard crinoidal crystalline; ostracods	3
Not exposed	1½
Limestone, hard grey (inverted dip)	4
Not exposed (apart from some sandstone) to fault	

The Kiln Pool Limestone has been worked from a shallow quarry in the right bank.

Rae Burn and tributaries. The area drained by the Rae Burn and its tributaries is mainly underlain by drift-covered Upper Border Group. Strata believed to lie a short distance above the Clattering Band are exposed in the upper reaches of the Rae Burn, 650 yd N.E. of Cragburn, where they dip at moderate angles to the north-west. A few yards north of a small fault the following section [4778 7661] can be seen:

	ft
Limestone, fine massive fawn ..	1⅓
Limestone, impure blue crinoidal	2¼
Shale, blue calcareous; limestone nodules, crinoids and productids	9
Shale, grey sandy	6

South of the fault [4775 7658] the section is

	ft
Sandstone, grey shaly; plant debris	7
Sandstone, roots at base ..	9
Limestone, blue-grey impure crinoidal; brachiopods	3⅓
Shale, blue-grey; fossiliferous at top, sandy bands at base	27

A little higher in the sequence, 16 ft of very shaly fossiliferous limestone [4774 7658] are overlain by flaggy sandstone, and still higher a 5-in coal crops out [4762 7653]. Half a mile upstream [4779 7735] an isolated exposure, mainly of sandstone, includes 10 in of carbonaceous shale and coal dipping at high angles to the north-west.

Downstream, towards Cragburn, there are discontinuous exposures of sandstone and shale, with a few thin grey limestones, as in the following section [4760 7626]:

	ft
Shale, dark grey; limestone bands	3
Limestone, hard, *Bellerophon sp.*	½
Shale with thin limestone ribs; crinoids and brachiopods	5

Another section of beds lying near the base of the Upper Border Group is seen immediately north of Birky Knowe as follows:

	ft
Sandstone	1
Not exposed	20
Shale, grey; traces of coal	2
Not exposed	2
Shale, dark; limy bands	3
Limestone, dark grey	⅓
Shale, dark; thin limestone bands	1½
Not exposed	3
Sandstone; partly ganister	3

Farther downstream faulted sandstones and shales emerge through the drift at Holy Well [4636 7553] and also near Sunnythwaite, in the right bank of the stream, where the following section south of a small fault [4569 7487] is recorded:

	ft
Sandstone, red-stained hard quartzitic	3 to 4
Coal, not seen, but said to be	2 to 3
Shale, dark, and light grey fireclay	about 6
Shale, soft	1
Fireclay and mudstone, grey	2
Not exposed; shale debris, dark	10
Limestone, impure reddish crinoidal	1½
Marl and red sandstone	—

About 70 yd downstream a sandy limestone, 3½ ft thick, crops out in the right bank and is repeated in the opposite bank [4570 7470] by the same small fault, which here follows the stream.

In the Shawstown Burn, 100 yd upstream from its confluence with the Rae Burn, are dark shales and a 6-in coal. Sandstones, shales and thin limestones are exposed discontinuously in the stream to within 150 yd of the road between Holywell Farm and Moss House.

Downstream from the Shawstown Burn confluence the Rae Burn runs entirely in drift for 2½ miles. South-east of Hemplands Bridge, however, reddened sandstone and mottled marls are seen dipping to south-east at between 20° and 30°. A coal at least 4 in thick crops out in the stream 100 yd S.W. of Jenkinstown, and another, 8 to 9 in thick, overlies pale grey fireclay on the east side of a fault, 200 yd south of the same farm. The position of these seams within the succession is uncertain.

Two coals, the higher of which is here called the Solport Coal, occur in an east–west stretch of the Rae Burn west of Solport Mill where the section [4634 7124] is

	ft
SOLPORT COAL	1
Mudstone, sandy; slightly rooty	2
Limestone, hard grey sandy ferruginous	⅓
Fireclay, shaly	1
Sandstone, shaly; bands of shale	2½
Shale, sandy; coal parting at base	5
Shale	1
Not exposed	3
Shale	½
Coal, shaly	1
Fireclay	½
Mudstone, shaly	2½
Sandstone, fine-grained grey shaly	5
Shale	2

There is no evidence to suggest that either seam has been worked, although the Solport Coal is reputed to have been excavated at one locality [4618 7123] to show a thickness of 33 in without exposing the roof. During the resurvey a thickness of 22 in was excavated—again without seeing the roof. Faulting to east and south, however, limits the area over which mining might be possible. The seam is believed to be the correlative of the Waverley Coal of the Archerbeck Bore: its absence at the appropriate position in the River Lyne is probably a result of oxidation.

South of Solport Mill and the Pallyards Fault, the Rae Burn flows down the succession over the intermittently exposed Shank Wood Sandstone and the calcareous beds which underlie it. Several small faults are present.

Hagg Beck. North of Haggbeck Cottage near the headwaters of Hagg Beck, coal has been worked at shallow depth over an area of several hundred square yards. It appears from the disposition of these workings that at least two seams were dug, but their thickness is not known: the only exposures in the beck are of sandstone and nodular planty shales dipping a little west of south at 15°. Higher in the sequence, a limestone of unknown thickness was once worked at a quarry [4730 7375] immediately south of Haggbeck Cottage, but the section is now obscured. The limestone and coals lie almost directly along the strike of the Whiteholme Limestone, and the two underlying thin seams exposed in the Black Lyne, 270 yd S.E. of Hagg Farm.

Farther downstream the Hagg Beck passes over downfaulted Liddesdale Group rocks and then over drift which extends almost as far as the confluence with Bells Burn. This burn traverses reddened sandstones, shales and thin hard crinoidal limestones, the exact horizons of which are uncertain, but which would seem from the prevalent southerly dip to lie below the position of the Solport Coal. About 100 yd below the confluence is a small syncline formed by 7½ ft of hard grey sandy limestone overlain by sandstones and underlain by mudstone and sandy micaceous shale. Reddening is again evident at the road bridge north-east of Solport Mill, where a little more than 1 ft of red, impure limestone rests on 2 ft of fine-grained, grey sandstone with marly partings. J.B.W.D.

BLACK LYNE CATCHMENT

Exposures in the Black Lyne, between the mouth of Sleet Beck [497 757] and the White Lyne confluence [496 730], provide sections which range from below the Clattering Band to above the Blacklyne Bridge (Kiln Pool) Limestone, and which are interrupted only by minor gaps and by the Dappleymoor Fault. North of the fault the rocks are grey, but to the south reddening appears at the horizon of the Hagg Coals and increases in intensity up to the Whiteholme Limestone: the higher strata—particularly the limestones and shales—are uniformly deep reddish purple.

Between Wickerthwaite and the Dappleymoor Fault. The section exposed in the Black Lyne between Wickerthwaite and the Dappleymoor Fault includes the uppermost 200 ft of Middle Border Group (p. 90) and succeeding measures extending from the Clattering Band to near the top of the Cumcrook Limestone: it is detailed in Appendix I (p. 296) and Pl. V (Section BL.2). The Clattering Band is represented by 8 ft of fine grey sparsely fossiliferous limestone [4987 7511]. It is succeeded by 25 ft of shales which include a thin limestone, and which are overlain in turn by the seatclay of the 9-in Oakshaw Coal. The overlying Oakshaw Limestone is 16 ft thick and contains hard bands resistant to weathering, but there is no sign of the tuff band seen at the type locality and to the north-east of Dodgsontown (pp. 120–1). Tuffaceous material does, however, occur about 50 ft higher in the sequence where it forms the top of an 8-ft limestone exposed downstream [4991 7504]. This limestone also contains small red-weathering patches and rare bellerophontids. The succeeding beds are mainly arenaceous and the next fossiliferous horizon is represented by 15 to 16 ft of dark shales containing thin limy ribs which have yielded *Dyscritella nana*. The section is exposed in the right bank where it is interrupted by a small fault. Although the Lower and Upper Netherhill seams of this section are only 6 in thick they may locally be thicker, for the Lower has been dug from a small adit [4983 7472], while on the left bank and some distance into Cumcrook Wood, are several old shafts presumably sunk to the Upper.

In the river the Upper seam is succeeded by 8½ ft of dark shales and these are separated by a gap estimated at approximately 50 ft from the next limestone which is 5 ft thick and exposed in the left bank [4991 7463] east of a small fault here following the course of the river. Higher in the sequence the Bullrigg Sandstone forms a small overhanging cliff in the right bank [5003 7457] where it consists of soft shaly sandstone alternating with hard whitish ganister bands. The sandstone is capped by 5 ft of fine grey splintery limestone which forms a small waterfall. It is followed in upward succession by 25 ft of very sandy shales containing bands of ganister and three 4-in coals which probably represent the Lawston Linn Coal of the Liddel. Above them and forming the base of another cliff is a 2-ft hard, grey, slightly earthy limestone striking parallel with the stream. Sandstones and shales form the overlying cliff together with a 3-in coal which lies 10 ft above the limestone. The Cumcrook Limestone crops out near the top of the cliff and is almost inaccessible. It consists of 30 ft or more of limestone and calcareous sandstone, crinoidal throughout.

The sequence is interrupted at the Cumcrook Limestone by the Dappleymoor Fault, the plane of which can be seen dipping to the south-west at 75° in the right bank cliff [4994 7455] and crossing the river [5001 7449]. The downthrow here is at least 200 ft to the south-west, although Garwood (1931, pp. 124–5) believed it to have been to north-east. South-west of the main fracture are a number of sub-parallel minor faults with associated cross-faulting.

The Oakshaw Coal Basin. The small, well-defined Oakshaw Coalfield covers an area of about 1½ square miles. It is bounded to the north by the curving outcrop of the Clattering Band and to the south-west and south-east by the Dappleymoor Fault and Goat Island–Lyne Thrust, respectively.

The Clattering Band is well exposed in the right bank of the Black Lyne (loc. 70f), where it has a varied fauna including colonies of *Lithostrotion portlocki* and *L. martini* in positions of growth (Pl. IVA). *Punctospirifer scabricosta* North and *Stenoscisma isorhyncha* are common, as is a hitherto undescribed species of *Semiplanus*. On the opposite side of the river the overlying Oakshaw Limestone has been worked for road metal and the composite section in the quarry and river is as follows:

	ft
Shale and thin CROW COAL	6
Shale, thin limestone ribs containing abundant *Productus garwoodi*	4
Limestone, hard massive; in two beds of equal thickness separated by a thin band of fossiliferous shale	4
Limestone, tuffaceous hard fine-grained	½
Tuff, soft calcareous ..3 to 4 in	¼
Tuff, hard calcareous ..2 to 3 in	¼
Tuff, coarse greenish; rare shells 8 to 9 in	¾
OAKSHAW LIMESTONE (loc. 71a)	
Limestone, massive; thin shaly partings	11
Limestone, shaly, hard laminated calcareous shales	12
Shale	1
Not exposed (includes OAKSHAW COAL at top)	8 to 9
Shale and thin shaly limestones	12
CLATTERING BAND	
Limestone, fossiliferous shaly	2½
Shale, fossiliferous calcareous	3

These measures are repeated at several localities along the strike, downstream towards Dodgsontown. The Oakshaw Coal attains a maximum thickness of 24 in at Oakshaw Ford where it was worked from the old Oakshaw Colliery and as recently as the late 1940's from an adit in the quarry (loc. 71b). It was also worked until about 1947 from an adit at the rear of the Roadhead Public Hall [5196 7528]. No analyses are available, but Smith (1912, p. 154) states that it is of poor quality with a high ash content. It had, nevertheless, a ready local sale as household fuel.

A line of old shafts—probably dating from the first half of the 19th century—extends north and east of Nether Oakshaw. Older bellpits are also present on the dip-slope north of the river [5067 7603].

The seam thins rapidly to the west of Oakshaw Ford. As compared with a thickness of 24 in measured in the right bank of the river [5087 7602] it is only 15 in where it re-crosses the stream north-east of Dodgsontown Farm and it is further reduced to 9 inches in the river a quarter of a mile south of Dodgsontown Ford [4989 7510]. At the last locality there is no shale intervening between the coal and the overlying Oakshaw Limestone. East of Oakshaw Ford the seam deteriorates, and in the sike [5210 7585] immediately south-west of Whintingstown it is represented largely by carbonaceous fireclay as seen in the following section:

	ft
OAKSHAW LIMESTONE	
Limestone, flaggy	3
Mudstone, shaly; fireclay at base	8
Fireclay, shaly carbonaceous	1½
Fireclay; coaly partings	1¾
Fireclay, carbonaceous	¼
Mudstones, nodular shaly	15
CLATTERING BAND	
Limestone	2

Flooding seems to have caused the abandonment at relatively shallow depths of many of the old coal workings as well as the most recent adit at Oakshaw Ford Quarry. No plans of the latter exist, but the outcrop of the North Meadow Sandstone [510 759] probably approximates to the southern limit of workings. There should be reserves to the south of this line but no information is available as to quality and thickness of the seam either there or in the direction of Kinkry Hill and Roadhead.

The tuff overlying the Oakshaw Limestone reaches its maximum exposed thickness of 2 ft 10 in on the western limb of the syncline in the right bank of the Black Lyne [5072 7594]: on the left bank [5048 7577] it is split into two 3-in bands about 3 ft apart. In a ditch [5183 7577], north-east of Nether Oakshaw, it comprises 8 to 9 in of tuff and breccia infilling fissures in the underlying shale and containing fragments up to 3 in diameter.

The 'Crow' Coal (Smith 1912, pp. 154–5) is about 8 in thick on both limbs of the syncline. Overlying beds up to the Cumcrook Limestone form crescentic outcrops which can be followed by features over most of the ground. The North Meadow Sandstone, which gives rise to one of these features, is exposed a few yards upstream from the mouth of Nether Hill Sike. The Lower and Upper Netherhill coals, 6 and 10 in thick respectively, crop out in Netherhill Sike [5070 7550 and 5076 7541] and have been worked nearby, though the Lower seam is very shaly. According to Smith (op. cit., p. 153) the Upper seam attains a maximum thickness of 18 in and is almost vertical near Kinkry Hill, but this observation does not accord with moderate dips observed at the surface and encountered in the Roadhead drift [5196 7528]. It seems possible that Smith confused the Upper Netherhill Seam with a seam of Middle Border Group age worked in Parkfoot Sike, south-west of Badds and south of the Goat Island–Lyne Thrust. The Cumcrook Limestone crops out below thin drift along Bull Rigg and large detached blocks are seen [5068 7473 and 5131 7415] close to the Goat Island–Lyne Thrust.

The highest beds in the basin are exposed in Farloan Sike. Several feet of calcareous shale near the head of the sike (loc. 72a) contain a fauna similar to that of the Clattering Band, which is at least 550 ft below. The shales are overlain by a thin limestone and by other fossiliferous shales. A hard limestone not exposed in the sike is represented by abundant loose blocks crammed with *Bellerophon latisulcatus* and other fossils (loc. 72b). This limestone has not been identified in the White Lyne and it appears to be cut out by the Dappleymoor Fault in the Black Lyne.

South of the Dappleymoor Fault. South of the Dappleymoor Fault and west of the Black Lyne the measures appear to be folded into a broad anticline complementary to the Oakshaw Basin. A note on one of the old field maps suggests the possibility of old workings in the Oakshaw Coal in a field north of Row Farm.

The lowest beds on the southern side of the fault are exposed in the river at the mouth of Farloan Sike [5017 7431] where they comprise

	ft
Limestone, compact grey	4
Shale, grey calcareous; abundant *Bellerophon sp.* (loc. 72c)	1
Shale, grey	6
Shale, carbonaceous; coal streaks	1
Fireclay, grey	1

The limestone at the top of this section is also exposed in the Back Burn [4957 7412]. It should not, however, be confused with another limestone overlying a *Bellerophon* shale exposed in the Black Lyne, 720 yd S.W. of Cumcrook Farm as follows:

	ft
Sandstone and shale (cliff in right bank) [4999 7436]	—
Coal (canneloid) and carbonaceous shale	1¼
Fireclay	½
Shale, sandy grey	6 to 7
Sandstone, shaly flaggy	12
Sandstone, massive; thickening abruptly to south-east	1 to 3
Shale, carbonaceous; coal partings	¼
Fireclay-mudstone	½
Sandstone, grey rooty argillaceous	4½
Sandstone, greyish white rooty; shaly at top	9
Sandstone, grey and purplish massive; rare shaly bands	12
Sandstone and shale	6
Limestone, grey slightly earthy; crinoidal; *Lithostrotion sp.* and brachiopod moulds	12
Shale, grey; abundant *Bellerophon sp.*	1
Shale, calcareous	10
Shale, sandy; carbonaceous bands	6 to 7

	ft
Sandstone, blue yellow-weathering hard rooty	18

A fault terminates this section at [4999 7445].

The correlation of these beds is made uncertain by the faulting which separates them from the two long sections (BL.2 and BL.1 of Appendix I and Pl. V) to north and south respectively. It is presumed, however, that they lie no great distance above the Cumcrook Limestone and below the beds exposed at the mouth of Farloan Sike.

The remainder of the section in the Black Lyne, repeated by small-scale step-faulting at the base, is detailed in Appendix I (Section BL.1, p. 297 and Pl. V). One of the lowest beds is a 10-ft limestone which contains *Lithostrotion martini*, *Syringopora sp.* and *Bellerophon sp.* and which strikes diagonally across the river (loc. 70c). About 36 ft higher in the sequence another limestone, 7 ft thick, crops out at the mouth of the Back Burn (loc. 70b). Two thin coals can be seen in the right bank south-east of Hagg Farm [4968 7374]. The beds in the roof of the upper 9-in coal are reddened, but the underlying beds down to the roof of the lower 5-in seam are not.

The Whiteholme Limestone, which is believed to be the correlative of the Pink Pool and Lynecrook limestones, is exposed at a bend in the river [4976 7363]: it also crops out on the other limb of a small faulted syncline about 140 yd downstream (loc. 70d) where it contains *Lithostrotion pauciradiale* (McCoy). The limestone is overlain on the left bank by crags of massive sandstone up to 50 ft high. This sandstone extends up Malls Burn past Whiteholme Cottage. It is overlain in the Black Lyne by shales, sandy shales and a few thin limestones which are folded into a plunging anticline and a complementary syncline just downstream from Black Lyne Bridge. Some 230 yd south of the bridge the reddened Blacklyne Bridge (Kiln Pool) Limestone, 8 ft thick, contains *L.* aff. *martini* (loc. 70g). The highest beds of the sequence occur around the confluence of the rivers Black Lyne and White Lyne: they consist principally of sandy shales with calcareous bands including 2 to 3 ft of red limestone at the confluence itself.

North of Oakshaw Ford. North of the Black Lyne–Bailey Water confluence a triangular tract of Upper Border Group strata is bounded by the Todholes Fault to the south and by the Bellevue and Black Pool faults to north-west and north-east respectively. In the centre of this tract sandstone features delineate a syncline folded along a north-north-westerly axis passing through Holehead. Other folding is suggested by southerly dips in the Bailey Water, west of Roanstrees, and by south-westerly dips in the Black Lyne, south-west of the Nook.

An impure coal, 4 in thick, overlies 1 ft of fireclay in the Bailey Water, 250 yd N.W. of Roanstrees, and a little farther downstream [5161 7831] the following section can be seen:

	ft
Shale, grey rubbly; rare plants ..	6
Sandstone, light grey medium-grained current-bedded ..	15
Shale, grey; thin shelly partings ..	22½
Shale, dark grey; ostracods ..	6
Limestone, shaly; crowded with bivalves	½
Shale, grey calcareous	11
Limestone, grey impure	1
Not exposed (?limestone) ..	2
Limestone, grey impure; ostracods	2
Not exposed	3½
Sandstone, light grey medium grained	12½
Shale, grey calcareous; thin nodular limestone bands	9
Sandstone, greenish grey flaggy	6

Still farther down the Bailey Water [5157 7818] 3 ft of planty shales overlie 1 ft of impure limestone. The highest beds exposed in this stretch of river consist of at least 20 ft of medium-grained, current-bedded sandstone [5157 7814].

There are several exposures of the Upper Border Group in the horseshoe bend in the Black Lyne, south-west of the Nook. An east–west fault seen in the right bank [5193 7788] appears to have a southerly downthrow but the amount is not known. A section measured in the right bank [5188 7789] south-west of Nook Farm is:

		ft
Sandstone, grey ganisteroid ..		2
Alternating bands of grey sandstone and dark grey shale; a few fossils		2
Not exposed; thickness unknown		?
Shale, soft grey		1
Shale, black carbonaceous	2 in	⅓
Coal	2 in	

	ft
Shale, rusty-weathering black ..	1½
Shale, hard grey sandy rubbly ..	1

The location of these beds within the Upper Border Group succession is uncertain. The stratigraphical position of the following sequence, exposed in the right bank, on the north or upthrow side of fault (loc. 70h), is similarly indeterminate:

	ft
Limestone, shaly, and limy shale in alternating bands; not all exposed; fossiliferous	5
Not exposed	?
Shale, dark grey; nodular and calcareous at base	1
Limestone, grey fine crystalline ..	1

On the southern side of the fault the section is

	ft
Sandstone, light grey to brownish flaggy; shaly at base	3
Shale, dark grey sandy; plant debris	2
Shale, dark grey; fossiliferous calcareous bands	3½

Some 20 yd upstream from the fault, and still on the right bank, 1½ ft of calcareous shale with limestone nodules are overlain by 11½ ft of sandstone and shales containing 1 in of coal. The next exposure upstream is at a bend in the river north of Mid Todholes, where reddened sandstone, shales and a 2-in coal are contorted in proximity to a branch of the Todholes Fault.

Exposures in a 250-yd stretch of the river west of Blackpool Gate Bridge include thin ostracod limestones with associated thin coals. The limestone in the following section [5304 7768] strikes diagonally across the stream:

	ft
Sandstone, soft current-bedded ..	12
Shale, grey	⅓
Coal and coaly shale	½
Shale, grey rooty	1¾
Sandstone, brown-weathering rooty	1
Shale, grey sandy; plants ..	3
Limestone, fine grey barren ..	½
Shale, rubbly sandy	1¼
Shale	½
Sandstone, light grey	3
Shale, grey sandy	4

Measures exposed in the right bank, 100 yd upstream from the last locality, are:

	ft
Shale, dark grey; carbonaceous at base	½
Coal and coaly shale	¼
Shale, grey rooty	2
Shale, sandy calcareous; ostracods and plant debris	½
Shale, dark grey; partly sandy ..	5½
Coal and carbonaceous shale ..	¼
Shale, rooty	1
Shale; thin bands of flaggy sandstone	5

About 90 ft of shales with several thin limestones, a few thin sandstones and three 2- to 4-in coals crop out in the stretch of river extending for 70 yd downstream from Blackpool Gate Bridge. The fauna consists mainly of ostracods with a few bivalves and the position of the section within the Upper Border Group sequence is uncertain. Dips are steep towards the north-west, and near the bridge they pass through the vertical and become inverted. Near the Todholes Fault the beds are vertical.

Crook Gill. Between Leagair Quarry (p. 114) and the Kershope Fault, Upper Border Group strata crop out at several localities in Crook Gill and around Gillhead. In Crook Gill (loc. 73) productids and crinoids have been obtained from an 8-ft bed of calcareous shales with thin limestone ribs: Miller, on the Old Series field map, records *Lithostrotion sp.* from the same locality. Two limestones crop out in the tributary farther north: one is 6 in thick and is possibly algal; the other, 25 yd downstream, is 1 ft thick and is a crystalline, crinoidal rock. Miller, on the Old Series field map, recorded a 4-ft coal at the side of an old track [4883 7942], but this seam was not visible during the resurvey.

Harry's Sike and Goose Sike. Exposures in Harry's Sike and Goose Sike, about a quarter of a mile west of the Dog and Gun Inn, are assigned to the Upper Border Group. In Harry's Sike they consist of sandstones and shales which are intruded by a volcanic neck (p. 245). In Goose Sike they include at one locality [5035 8235] thin fossiliferous limestones; at another locality [5058 8219] a 4-ft pale grey, fine-grained limestone displays circular markings on brown-weathering surfaces.

Christianbury Crag. Christianbury Crag is formed of at least 25 ft of medium-grained finely current-bedded sandstone, with coarser bands and a few small angular pebbles of quartz. Weathering has imparted a characteristic 'potholed' appearance to the crags and to the associated large loose sandstone blocks. The sandstone is correlated with a similar bed cropping out at Sighty Crag, about 2 miles to south-east, and is placed near the base of the Upper Border Group purely on structural grounds. J.B.W.D.

WHITE LYNE CATCHMENT

The long continuous section of nearly vertical strata exposed in the River White Lyne (Appendix I, pp. 307–14) include more than 1400 ft of Upper Border Group. They are deeply and uniformly reddened and, at several localities, are exposed for examination and fossil collection only during periods of prolonged drought. Moreover, sections are disturbed in places by groups of small east–west tear faults so that correlation, beyond the limits shown graphically on Pl. V (Sections WL.1 and 2), is somewhat tentative.

A band containing *Productus garwoodi* occurs just above the top of the Oakshaw Limestone, but there is no trace of tuff. The overlying sequence up to the Cumcrook Limestone further differs from that in the River Black Lyne south of Dodgsontown Ford (p. 119) in the absence of coals and in the much greater development of trepostomatous bryozoa in the Bryozoan Limestones about 200 ft above the Oakshaw Limestone. The Cumcrook Limestone is seen in the river [5057 7320], but it is better exposed in Parkfoot Sike, 300 yd S.W. of High Parkfoot where a prolific fauna has been collected (loc. 74).

A short distance above the Cumcrook Limestone the Parkfoot Fault cuts out an uncertain thickness of strata including the measures exposed in Farloan Sike. The 150 ft of strata exposed in the White Lyne immediately downstream from the Parkfoot Fault consist mainly of sandstone. They are succeeded by five limestones, all disturbed by an east–west sinistral strike-slip fault which crosses the river bed at an acute angle just off the mouth of Parkfoot Sike. J.B.W.D.

CAM BECK–KING WATER CATCHMENT

The Kingbridge Limestone at the base of the Upper Border Group is repeatedly exposed in the King Water in a series of faulted strike-sections extending from the southern margin of the district to the mouth of the Trout Beck. The southernmost exposure of the limestone is in the river [5839 6803], 340 yd S.S.E. of Spotleybank, where it contains abundant colonies of *Lithostrotion martini*. It is overlain by current-bedded massive sandstone which crops out discontinuously from this locality up to the North Upper Denton Fault, three-quarters of a mile upstream. The fault repeats the lowest beds, so that in a distance of 500 yd upstream there are three more exposures of the Kingbridge Limestone. At the northernmost locality [5973 6859] the section is

	ft
Limestone, hard; colonies of *L. martini*	4
Shale, grey massive; rare fish scales and teeth	3
Coal, impure	¼

Upstream towards Snowden Close the overlying beds are again discontinuously exposed. They consist mainly of sandstone with subordinate shales and rare crinoidal limestones of which few are more than 1 ft thick. North of Snowden Close the river recrosses the sequence but higher beds—mostly sandstone—are repeated in the mouth of Jamie's Hill Sike. Some of these higher beds probably represent the Tinkler Crag and Crying Crag sandstones of sections to north-east (p. 125).

Between branches of the Waterhead Fault, the Kingbridge Limestone crops out at two further localities, both in the left bank of the stream [6030 6912 and 6027 6947]. It is also seen in the King Water [6114 6990] where it is affected by a small north–south fault. In Middle Shield Beck [6170 7029] the limestone is 4 ft thick as compared with a thickness of 12 ft, including a 5-ft shale band, in Spadeadam No. 3 Bore (Appendix II, p. 337).

Farther up the King Water the measures between the Kingbridge Limestone and

Tinkler Crag Sandstone are moderately well exposed. They are dominantly arenaceous, and include a 3-in coal overlying 12 ft of dark shales [6148 6995] as well as several thin bands of cementstone and calcareous sandstone. In the right bank of the stream, 80 yd S.W. of the mouth of the Middle Shield Beck, is the following section:

	ft
TINKLER CRAG SANDSTONE ..	6
Cementstone	2
Shale, grey; poorly exposed ..	15
Cementstone	1½
Sandstone	2¾
Shale, sandy	3
Sandstone	1¼
Shale, sandy	2¼
Sandstone, rubbly; rootlets ..	5

The Tinkler Crag Sandstone has been quarried extensively on the opposite side of the river and it contains two or more shelly and calcareous bands at the sides of the road leading to Moscow.

Upstream are faulted strike sections of the Crying Crag and Tinkler Crag sandstones, together with intervening beds, which include thick shales with carbonaceous bands and several thin calcareous horizons.

At Crying Crag the river abruptly turns and to the north-west the succession down to the base of the group is discontinuously exposed. It is shown graphically in Pl. V, Section K. Within this section are large blocks of calcareous, conglomeratic sandstone containing superficially reddened algal nodules; these blocks appear to be derived from a bed [6347 7155] below the Tinkler Crag Sandstone. The latter takes its name from this locality and is locally about 100 ft thick.

J.B.W.D.

LOWER IRTHING–TIPALT CATCHMENT

Gilsland Gorge. North of Gilsland the River Irthing flows through a precipitous gorge following a group of five sub-parallel north-westerly faults which coalesce to the south-east to form the Blenkinsopp Boundary Fault (Trotter and Hollingworth 1932, p. 8, fig. 1). These faults are distributed in a horst–trough–horst–trough arrangement (Fig. 22) giving rise to repeated exposure of the succession between the Lanercost and Upper Millerhill limestones.

The lowest bed consists of 3 ft of calcareous sandstone [6354 6904]. It is overlain by 120 ft of mainly arenaceous strata consisting, in upward sequence, of the Crammel Linn, Green Grove and Collering sandstones, with intervening shales or beds of limestone. The petrography of the sandstones is described on p. 217.

The Crammel Linn Sandstone attains a maximum thickness of 70 ft [6354 6904], but is very variable. In a cliff [6350 6812] forming the north side of a peninsula west of the Poppingstone, the upper part of the sandstone is replaced almost entirely by shales with bands of limestone and thin coals as follows:

	ft
GREEN GROVE SANDSTONE	
Sandstone, flaggy at base ..	8
Limestone, weathering yellow ..	2
Mudstone	1
Coal, and carbonaceous shale ..	⅓
Fireclay; shaly at base	3
Shale	12
Limestone	2
Shale	20
CRAMMEL LINN SANDSTONE	
Sandstone, massive ..	3 to 15
Shale; with thin coal	3
Limestone	2½
Coal	¼
Fireclay	3

From this locality the Crammel Linn Sandstone thickens rapidly to the east and south, cutting out the underlying beds (Fig. 22) until on the south side of this peninsula the sandstone is thick enough to occupy the whole of the river on both sides of the suspension footbridge. The spectacular waterfall at Crammel Linn is formed by the termination of the topmost 40 ft of this sandstone against the easternmost branch of the Blenkinsopp Boundary Fault.

In most places the strata between the Crammel Linn and Green Grove sandstones consist of 12 ft or more of shales with bivalves, together with a thin limestone and coal. The Green Grove Sandstone, averaging 15 ft in thickness, is overlain by up to 10 ft of shales locally containing a thin limestone band, and these are succeeded by the Collering Sandstone, which has a maximum thickness of 30 ft and is markedly calcareous at the top.

The measures between the Collering Sandstone and the Lower Millerhill Limestone include two thin limestones, the lower of which is underlain by a thin coal, and the 16-ft Poppingstone Sandstone. The sandstone is locally calcareous and forms the faulted cliff immediately behind the Popping Stone. The Lower Millerhill Limestone crops out opposite the Popping Stone, in the mouth of Greenhole Sike, where it is 25 ft thick.

River Irthing: Crammel Linn to Wiley Sike. Between Crammel Linn and Wiley Sike the River Irthing crosses an unbroken sequence extending from the middle of the Crammel Linn Sandstone up to the Leahill Limestone (Appendix I, p. 229, and Pl. V, Section I.1). The sequence includes a thin coal believed to be the equivalent of a seam worked in the Upper Irthing valley at Throssburn Foot (p. 129) and an attenuated representative of the massive Spy Rigg Sandstone of the Upper Irthing valley (p. 129). Measures above the sandstone are best seen in the Crammel Burn, south of Forster's Hill, but they are also exposed in the Irthing farther north. The Wiley Sike Limestone, of which only 6 ft are seen in the burn, is fully exposed over a thickness of 15 ft in the river: it was also encountered immediately beneath drift deposits, at a depth of 84 ft in the Wiley Sike Borehole [6674 7154].

River Irthing: near Bell's Braes. Measures belonging to the upper part of the Upper Border Group form isolated exposures on both sides of a fault at Bell's Braes (loc. 77a). The following section [6898 7166] was measured on the left bank of the River Irthing, west of the fault:

	ft
Limestone, hard grey; weathering brownish; '*Camarotoechia*' cf. *pleurodon*, *Spirifer* cf. *trigonalis*, smooth spiriferids, costate productids, *Bellerophon sp.* and *Aviculopecten sp.*	2 to 3
Shale	3
Sandstone, partly calcareous; *Fenestella sp.*, *Buxtonia sp. nov.*, '*Camarotoechia*' cf. *pleurodon* and *Punctospirifer scabricosta*	8 to 10
Not exposed	6
Shale	2½

Also on the west side of the fault, but farther up the side of the hill, the following are seen:

	ft
Limestone, sandy; *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Echinoconchus* cf. *punctatus*, *Productus*?, *Spirifer sp.*, *Naticopsis*?, *Leiopteria divisa* and smooth pectinids	9
Not exposed	6 to 7
Limestone, sandy; *Buxtonia sp. nov.*, '*Camarotoechia*' *pleurodon*, *Productus*?, *Punctospirifer scabricosta*, *Leiopteria divisa* and costate pectinid fragments	2½

East of the fault, on the right bank of the river, the section is

	ft
Limestone, hard; *Bellerophon sp.*	1
Shale; plant remains	3
Limestone, yellow-weathering; *Bellerophon sp.* and ostracods	1
Shale; bivalves	—

River Irthing: Sunday Burn to Lampert. Farther upstream, where the river flows south-south-eastwards, a continuous section from the Spy Rigg Sandstone to about 60 ft above the Leahill Limestone is exposed between the mouth of Sunday Burn and Sundayburn Linn (Appendix I, p. 301; Pl. V, Section I.2). The Spy Rigg Sandstone, including a thin shale band near the top, is 70 ft thick in this section. It is overlain by about 50 ft of shales which include richly fossiliferous calcareous ribs equated with the Wiley Sike Limestone about 20 ft up from the base. The Appletree Limestone, another 100 ft higher in the sequence, is truncated by a small fault at outcrop [6897 7268] in the left bank of the river. It is separated from the Leahill Limestone above by 46 ft of shales with thin limestones and two coals 1 to 3 in thick. The upper coal shows signs of partial erosion before deposition of the overlying limestone (Fig. 24). The Leahill Limestone is 10 ft thick and is overlain by 1 ft of shales on the left bank [6895 7256]. On the opposite bank, however, an overlying sandstone transgresses the shales in a north-westerly direction and rests directly on top of the limestone. The highest measures include a 14-in coal which has been worked from adits in the river bank and from bellpits on both banks farther inland. The coal is overlain by 4 in of ostracod shale and by an 18-in limestone which lies at the base of 10 ft of shales containing marine shells. The 4-in ostracod shale is here called the Gavelock Band: it is also recorded in Chapel-

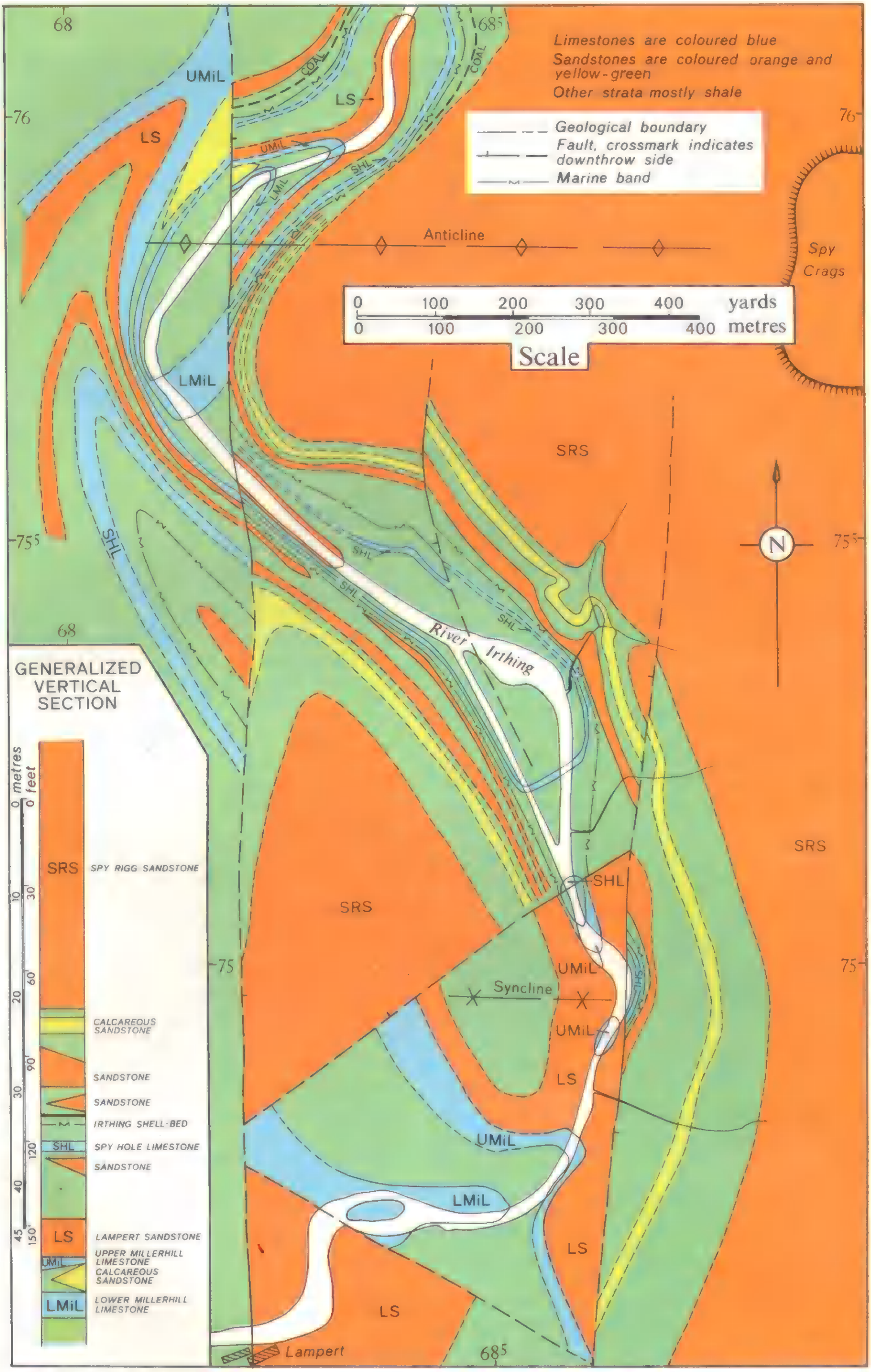


FIG. 23. *Sketch–map showing outcrops of Upper Border Group strata in the River Irthing*

1500/68

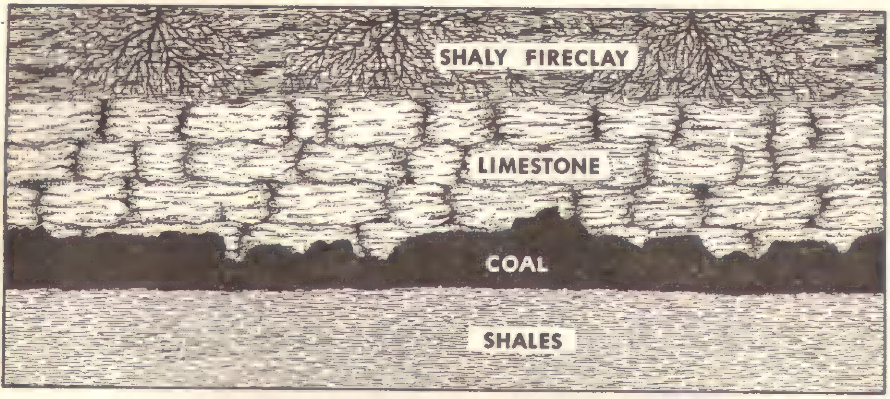


FIG. 24. *Sketch of the junction between a thin limestone and underlying coal: strata overlying the Appletree Limestone in the River Irthing*

burn No. 2 Bore at 635 ft (Appendix II, p. 327) and was observed in the core of the Archerbeck Bore at 3071½ ft.

A north-easterly fault ends the section at the upstream end of Sundayburn Linn. Strata below the Spy Rigg Sandstone are exposed north of the fault. The section [6853 7329] nearest the fault is as follows (loc. 77d):

	ft
Boulder clay, brown	30
?IRTHING SHELL BED	
Shale, dark; an ironstone band 3 ft above base; abundant *Naiadites crassus*, ostracods and plants	8
Sandstone, rooty	2½
Shale, micaceous sandy; *Naiadites sp.*	6
Sandstone, slightly calcareous; shale parting	2
Shale, dark grey planty; becoming sandy towards base; *Fenestella matheri*, *Buxtonia sp.* spines attached, '*Camarotoechia*' *sp.*, *Punctospirifer scabricosta*, *Myalina pernoides*, *Polidevcia attenuata*, *Streblochondria sp.* and ostracods ..	4
Coal	¼

There are no exposures for 20 ft below the coal and the succession is then continued in the following downward sequence in the left bank [6844 7352; loc. 77e], 300 yd W.N.W. of Tod Hole:

	ft
Boulder clay	—
Shale, dark; plant remains ..	10
Coal	¾
Fireclay	¼
Shale, dark; hard bands at base	4
Shale, dark grey planty; fragmentary productids, *Naticopsis sp.* and ostracods including *Paraparchites sp.*	2
Shale, hard sandy	1
Shale, dark grey partly calcareous; hard, slightly ferruginous limestone concretions containing *Fenestella sp.*, turreted gastropod indet., *Leiopteria divisa*, *Polidevcia attenuata*, *Promytilus*? and orthocone nautiloids	6½
Mudstone, dark grey shaly; abundant *Bucanopsis striata*, *Hypergonia sp.*, *Naticopsis sp.* and *Promytilus*?	3
Limestone, sandy crystalline; plant remains, '*Camarotoechia*' *sp.*, *Aviculopecten sp.*, and *Myalina pernoides*	1 to 1½
Shale, dark grey; sandy limy ribs; '*Camarotoechia*' *sp.*, *Aviculopecten* cf. *interstitialis*, *A. sp.*, *Myalina* cf. *pernoides* and ostracods	3

A still lower horizon is represented by the sandstone which crops out in Linen Sike [6842 7385].

River Irthing: Lampert to Shank End. North of Lampert (Fig. 23) the beds are disposed in a syncline and complementary anticline with approximately east–west axes. The sequence exposed in the river ranges from the Lower Millerhill Limestone, in the core of the anticline, up to the base of the Spy Rigg Sandstone: it shows much lateral variation in lithology and is interrupted and repeated by the northerly Spy Rigg and Lampert faults together with associated cross-faulting.

A small fault [6832 7471], 200 yd N.E. of Lampert, brings Lower Millerhill Limestone to the north against horizontal Lampert Sandstone to the south. Measures above the Lower Millerhill Limestone are exposed upstream from this locality where they form the following section (loc. 77f), broken only by the Spy Rigg Fault:

	ft
Sandstone, with uneven base	15
Shale, dark; thin limy and irony bands; '*Camarotoechia*' *sp.*, *Punctospirifer scabricosta*, *Aviculopecten sp.*, *Myalina pernoides* and *Polidevcia attenuata*	11
IRTHING SHELL BED	
Limestone, sandy; crowded with *Naiadites crassus* and adherent bryozoan and *Spirorbis sp.*; some '*Camarotoechia*' *sp.*	¼
Shale; thin coal near top; plant remains	3½
Sandstone, slightly calcareous flaggy; thickening to north	3
Shale	1⅓
SPY HOLE LIMESTONE	
Limestone, shaly; *Lingula sp.* [large], *Limipecten sp.* and ostracods including *Paraparchites sp.*	2½
Shale, grey sandy calcareous at top	3
Sandstone, hard grey slightly calcareous; *Productus garwoodi*	2
SPY RIGG FAULT [6867 7500], cutting out	20
Limestone, detrital sandy; shell debris	1½
Shale, sandy; sandstone ribs	7 to 8
LAMPERT SANDSTONE	
Sandstone, massive; flaggy towards top	12
Shale	1⅓
UPPER MILLERHILL LIMESTONE	
Limestone, grey shaly; sparse plants, *Bellerophon sp.*, *Naticopsis sp.* and *Composita sp.*	4½
Shale, black	1
Mudstone, shaly black; ostracods at base	1¼
Shale, black calcareous; ostracods	¼
Shale, carbonaceous	½
Coal	¼
Fireclay, grading down into	1
Shale, calcareous grey sandy; *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Productus*? and ostracods	4
LOWER MILLERHILL LIMESTONE [6832 7471]	
Limestone, hard bedded; against fault; *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Productus?* and *Naticopsis sp.*	1

Beds from the Irthing Shell Bed up to the base of the Spy Rigg Sandstone are seen in the small tributary in the left bank of the River Irthing [6861 7538; loc. 77g], 960 yd N.E. of Lampert as follows:

	ft
SPY RIGG SANDSTONE	—
Not exposed	up to 10
Shale	2
Sandstone, massive calcareous; *Fenestella sp.*, trepostome indet., *Composita* cf. *ambigua*, *Productus garwoodi*, *Punctospirifer scabricosta*, *Spirifer sp.*, *Polidevcia attenuata* and *Sanguinolites sp.*	6
Fireclay	1
Shale with calcareous ribs; *Polidevcia attenuata*	3
Sandstone, massive brownish	12
Limestone, sandy; '*Camarotoechia*' *sp.*	1
Shale, dark slightly sandy	11
Sandstone, flaggy	1½
Shale, grey; sandy ribs; *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*	10
IRTHING SHELL BED	
Shale, calcareous; '*Camarotoechia*' *sp.* and abundant *Naiadites crassus*	1
Shale, calcareous at top	4

The rapid lateral variation in lithology is exemplified in the right bank [6835 7543; loc. 77h], 1000 yd N. by E. of Lampert, where the section is

	ft
Shale	—
Sandstone, massive; lenses out a few yards to the north-west and reappears 60 yd farther to north-west	7 to 8
Shale; sandy ribs; '*Camarotoechia*' *sp.* and *Aviculopecten sp.*	7
IRTHING SHELL BED	
Limestone, flaggy; '*Camarotoechia*' *sp.* and abundant *Naiadites crassus*	1½
Shale, calcareous; limestone ribs	2
Shale	4

	ft
Shale, sandy; sandstone ribs which thicken northwards and replace the shale	3½
SPY HOLE LIMESTONE	
Limestone, grey; *Buxtonia sp.*, '*Camarotoechia*' *sp.* and *Schizodus sp.*	1⅓
Shale; carbonaceous layers; *Lingula* cf. *mytilloides*, *Spirorbis sp.* and *Bairdia sp.*	4

In the faulted core of the anticline west of Spy Rigg a thick wedge of calcareous sandstone takes the place of shale and increases the interval between the Upper and Lower Millerhill limestones adjacent to the Lampert Fault on its eastern downthrow side [6819 7594]: the wedge thins out 40 yd north-east of the fault [6824 7595; loc. 77i] where the section is

	ft
LAMPERT SANDSTONE	
Sandstone; '*Camarotoechia*' *sp.* and bivalves	5
Shale, sandy	1 to 2
UPPER MILLERHILL LIMESTONE	
Limestone, brownish; *Bellerophon sp.* and *Straparollus sp.* s.l.	6
Mudstone, calcareous; *Composita*? and ostracods	½
Shale, dark grey; planty towards top; *Lingula* cf. *mytilloides* and ostracods 1½ ft from top with *Paraconularia sp.*, '*Camarotoechia*' *sp.*, *Composita*?, *Hypergonia sp.*, *Aviculopecten* cf. *interstitialis*, *Leiopteria sp.*, *Myalina pernoides*, *Polidevcia attenuata* and ostracods 2 ft from base	7
Mudstone, shaly	5
LOWER MILLERHILL LIMESTONE	
Limestone, grey; *Fenestella frutex*, trepostomes, *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.* and *Schizodus sp.*	4
Shale, dark grey; *Buxtonia sp. nov.*, *Productus garwoodi*, *Pteronites sp.*, *Sanguinolites sp.*, '*Camarotoechia*' *sp.* and ostracods	1

On the other side of the fault, 300 yd downstream [6811 7567; loc. 77j] there is again no sign of the wedge of sandstone:

	ft
LAMPERT SANDSTONE	
Sandstone	8
UPPER MILLERHILL LIMESTONE	
Limestone, fine-grained unfossiliferous	1½
Shale, calcareous; limestone ribs; trepostomes, *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Modiolus sp.*, *Nothamusium radiatum* and ostracods	12
LOWER MILLERHILL LIMESTONE	
Limestone, massive; shaly in middle; *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Donaldina sp.*, gastropod fragments, *Leiopteria sp.* and *Edmondia sp.*	8½
Shale, grey; *Buxtonia sp. nov.* etc.	2
Limestone, hard platy	2

J.B.W.D.

On the west side of the Irthing, 400 yd S.W. of Shank End, the following section [6841 7636] is exposed in a tributary:

	ft
Coal smut	—
Shale	3 to 4
Sandstone, medium- to coarse-grained	1
Shale	2

This section is only a few feet above the Spy Hole Limestone, the northernmost exposure of which forms a tessellated pavement in the bed of the river [6842 7632], 500 yd S.W. of Shank End.

On the south side of the Irthing, 410 yd S.E. of Shank End Farm, the following section [6903 7640] is exposed:

	ft
Shale, coaly at top	12
Sandstone	1
Shale; sandstone ribs	1⅓
Sandstone	2
Shale, grey micaceous; sandstone ribs at top, occasional ironstone nodules	12
Mudstone, shaly carbonaceous; coaly films	2½
THROSSBURN FOOT COAL	2
Shale, grey micaceous; coaly at top	3
Not exposed	2
Limestone, fine-grained argillaceous (in river bed)	1

The lower part of this section, except for the limestone, is intermittently exposed on the east bank of the river from this locality as far north as Throssburn Foot, beyond which the river is entirely in drift as far as Whitehill Farm. D.A.C.M.

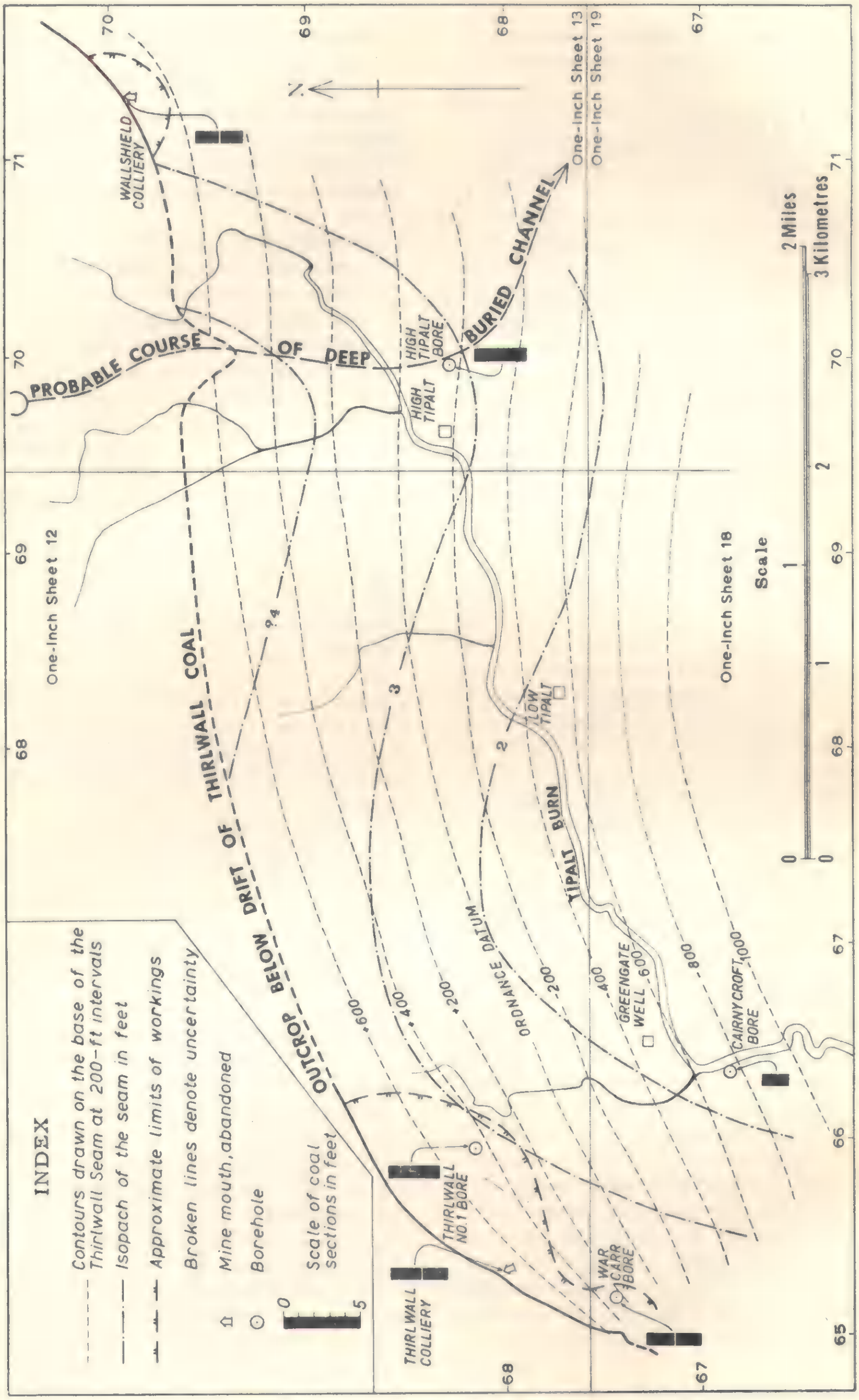


FIG. 25. *Isopachytes and contours of the Thirlwall Seam*

Spy Crags [6886 7569] rise to 1027 ft and provide a landmark visible for many miles; the 30-ft face of the crags is surmounted by two large residual perched blocks. Hereabouts the Spy Rigg Sandstone is probably about 120 ft thick and consists mainly of medium-grained massive sandstone in thick beds. A patch of bright green grass [6867 7578] suggests the presence of a calcareous bed.

In Shield Sike, 1300 yd S.E. of Spy Crags, there is an ancient coal working [6980 7502] which seems to lie within the Spy Rigg Sandstone. About 300 yd S.W. of this locality, on a small promontory bounded to north, east and south by Larey Sike, are the remains of an ancient British village consisting of fifteen hut-circles grouped about a larger rectangular foundation, but there is no evidence that the coal in Shield Sike was worked by the inhabitants of this early settlement.

Between the River Irthing and Tipalt Burn. In the moorland tract between the River Irthing and Tipalt Burn the highest measures of the Upper Border Group are covered by drift, apart from a few sandstone crags such as those at Burn Divot half a mile south of Bell's Braes. Until 1926 the Thirlwall Seam was worked half a mile east of West Nichold. According to Trotter and Hollingworth (1932, pp. 37, 43) the seam has a maximum thickness of 3 ft 10½ in, diminishing rapidly to south and west (Fig. 25); and has the following analysis: fixed carbon 56.93 per cent, volatiles 38.27 per cent, ash (in coke) 7.00 per cent. They quote yield per ton of coal as follows: gas 10.806 cu ft, tar 24.62 gal, benzole 2.62 gal, ammonia 7.82 lb and sulphur equivalent to 30.33 lb. The seam is believed to be more than 3 ft thick farther east, between Thirlwall and Wallshield, in the ground covered by the Bellingham (13) Sheet, but it has not been worked there because access is difficult. The seam is also reputed to have a poor (shale) roof. J.B.W.D.

UPPER IRTHING CATCHMENT

Gair Burn headwaters. In Gair Burn [6180 8057 and 6180 8067], near the union of the headwaters, massive, fine- to medium-grained, current-bedded sandstone is exposed. In Gosling Sike [6177 8062] a few yards to the west, and slightly higher in the succession, is the following section:

	ft
Limestone, grey-brown argillaceous; ostracods	1
Shale, calcareous; *Punctospirifer sp.*, bivalves and ostracods ..	2
Limestone, grey argillaceous ..	½

Nearby [6167 8054] in Heather Sike, which flows east from Sighty Crag, 6 ft of flaggy, fine-grained sandstone with roots overlie a 1-ft grey limestone with shale partings and with shell and plant debris. These beds are a few feet above the previously described section, though variations in dip and strike together with discontinuity of exposure make the precise relations obscure. For 600 yd farther upstream [to 6113 8048] there are discontinuous exposures of shales, in part calcareous, with bivalves and ostracods.

In Jamie's Sike, the left bank tributary of Gair Burn, the following are exposed [6316 8093], 1½ miles N. of Irthing Head:

	ft
Shale, grey; fine-grained flaggy sandstone near base	4
Sandstone, grey flaggy fine-grained	1
Mudstone, grey shaly; small ironstone nodules; plant debris in lowest 4 in	6⅓
Coal, shaly	¼
Shale, carbonaceous	5
Coal, shaly	¼
Seatearth-mudstone, grey ..	1¼
Mudstone, grey	7
Limestone, pale grey; crinoid columnals, *Dyscritella nana* and *Punctospirifer scabricosta* (loc. 79)	¼

Gair Burn. Between 560 and 630 yd upstream from Irthing Head the following section is exposed in Gair Burn:

	ft
Shale and mudstone, grey; plants and roots	2
Shale, carbonaceous; coaly streaks	½
Mudstone, grey; plants and roots	⅓
Shale, carbonaceous; coaly at base; 1½ in of coarse-grained green pyritic sandstone near the base ..	1
Fireclay-mudstone, grey	1½
Shale, carbonaceous	⅓
Fireclay-mudstone, grey ..	about 6
Shale, carbonaceous; coaly partings	⅔
Fireclay-mudstone, grey	2
Not exposed	about 6

	ft
Limestone, grey weathering yellow; well-jointed, argillaceous, fine-grained	2
Not exposed	about 10
Sandstone, thin-bedded fine-grained siliceous ferruginous	2
Mudstone, pale grey; roots	6
Shale, grey carbonaceous	2
Mudstone, pale brown; a few roots at top; becoming grey and silty in lower part	2
Limestone, grey weathering yellowish brown fine-grained argillaceous; *Cleiothyridina sp.*, *Myalina sp.* and ostracods (loc. 78a)	1½
Shale, grey; plants and roots [6261 7896]	1½

The limestone near the base of this section weathers to a brown clay containing septarian nodules of hard calcareous siltstone up to 3 ft across. A vugh in one of the nodules was seen to be lined by aragonite surrounding a main infilling of brown crystalline dolomite, with nail-head calcite in the core. Other vughs consist of a boxwork structure composed largely of goethite or, in places, blue opaline chalcedony.

About 150 yd farther downstream [6273 7890] the following strata, believed to lie stratigraphically only a few feet above the top of the preceding section, are exposed on the left bank of Gair Burn:

	ft
Shale, carbonaceous	¾
Shale, grey rooty	2
Shale, grey silty; a few thin sandstone partings	2¼
Shale, coaly	½
Fireclay-mudstone, grey	1¾
Shale, grey very weathered; fragmentary shells	⅔
Shale, carbonaceous; ½-in coal	⅓
Fireclay-mudstone, grey	4

Still farther downstream, the burn flows through an unexposed stretch representing about 25 ft of strata before reaching a gorge at Malcolm's Still [628 788; loc. 78b], where the following sequence has been measured:

	ft
Sandstone, thin-bedded fine-grained; roots at top	3½
Shale, silty	1
Sandstone, irregularly bedded fine-grained slightly calcareous; nodular towards top; grey and argillaceous towards base; sparse crinoid columnals and brachiopod fragments	5
Limestone, grey sandy; crinoid columnals	½
Mudstone, grey silty	2
Sandstone, grey weathering brown fine-grained partly calcareous; shaly beds; crinoid columnals and shell fragments	6
Sandstone, thin-bedded fine-grained siliceous; a few thin shaly partings; micaceous in top 5 ft	about 40
Sandstone, false-bedded fine-grained siliceous; partly thin-bedded and partly massive	about 50
Sandstone, dark grey calcareous; *Buxtonia sp. nov.*, bellerophontid indet., *Straparollus sp.*, gastropods indet., *Leiopteria sp.* and *Polidevcia attenuata*	1
Shale, grey, micaceous; crinoid columnals, cf. *Palaeolima simplex* and ostracods	1⅔
Sandstone, grey rubbly fine-grained argillaceous and calcareous	1¾
Shale, grey micaceous and calcareous; *Fenestella sp.*, *Edmondia* cf. *sulcata* and ?*Pernopecten sp.*; a few thin sandstone partings towards base	9
Alternations of thin-bedded shaly fine-grained micaceous sandstone and grey micaceous shale	3
Mudstone, grey; *Lingula* cf. *squamiformis*, *Modiolus* cf. *latus* and ostracods	1⅔
Not exposed	1
Siltstone, grey calcareous	1
Limestone, hard grey argillaceous; *Bellerophon sp.*, *Aviculopecten sp.*, *Modiolus sp.*, *Myalina* cf. *pernoides*, *Naiadites crassus*, *Pteronites latus* and *Schizodus sp.*	1

Only a few feet above this section, a coal, here named Gair Burn Coal, was formerly worked from five small adits on the Cumberland bank [6284 7873]. Its thickness is unknown.

The next exposure downstream starts about 60 ft stratigraphically above the Gair Burn Coal, and is as follows [6287 7870; loc. 78c]:

	ft
Sandstone, thin-bedded fine-grained argillaceous calcareous; *Fenestella sp.*, *Aviculopecten sp.* and *Naiadites crassus* (near top)	about 16

	ft
Shale, grey micaceous; a few thin sandy partings; fossil debris at top and carbonized plant debris below	16
Sandstone, thin-bedded fine-grained calcareous; crinoid columnals in lowest 1 ft	6

The 300 ft of overlying strata which crop out downstream from this locality are represented only by disconnected exposures, almost all of thin-bedded, fine-grained sandstone. Above one sandstone, 180 yd N.N.E. of Irthing Head, is a 3-in coal with an 18-in shaly and carbonaceous seatearth. The highest bed in this area is a 45-ft sandstone exposed at Irthing Head [6288 7845] and in Gair Burn and Tarn Beck. The rock is thin-bedded, partly false-bedded, fine-grained, brown and poorly cemented. D.H.L.

Pike Burn, Padda Burn, Blind Sike. A fine- to medium-grained, flaggy sandstone, locally with irregularly contorted bedding, forms Slaty Pike, 1030 yd S.W. of Black Knowe Trig. Point [6370 8029]. Some 4½ ft of gnarled sandstone with irregularly contorted bedding are seen in the same bed 680 yd [6394 8089] to the north-east.

Block faulting in the area adjacent to the Antonstown Fault, near the headwaters of the Padda Burn, has repeated the outcrop of the same sandstone over an east–west belt at Maggot's Pike [6418 7950], and again about a quarter of a mile to the west-south-west [6380 7932].

The base of this sandstone lies a few feet above the following section [6423 7941] in Padda Burn immediately east of Maggot's Pike:

	ft
Shale, sandy grey micaceous	10
Not exposed	6 to 10
MAGGOT'S PIKE LIMESTONE	
Limestone, argillaceous shelly rusty-weathering dark grey thinly bedded	about 4
Shale	1

A feature of the Maggot's Pike Limestone is the presence of black carbonaceous pellets or blebs of carbonaceous material; the rock also contains *Aviculopecten sp., Paraparchites sp.* and indeterminate bivalve fragments. Farther upstream, small exposures of shale, calcareous sandstone and flaggy, fine-grained sandstone are seen as far north as the Reamy Rigg Fault at [6425 7968].

In the Pike Burn, 1650 yd N.N.W. of the confluence with the River Irthing, Miller noted, in the original survey, an argillaceous limestone containing spiriferids overlain by a thin sandstone with calcareous courses containing *Stigmaria* [6327 7975]. These beds, like those of Maggot's Pike, occur in a faulted block. Their stratigraphic position is thus obscure, but they probably underlie the Maggot's Pike Limestone and the sandstone of Slaty Pike.

The north-easterly Pikeburn Fault strikes across the area south-west of Black Knowe and cuts out strata younger than the sandstone of Slaty Pike. These strata are, however, represented in the higher reaches of the Padda Burn where a series of beds is seen dipping into the north side of the Antonstown Fault. They include a fine-grained, predominantly massive, white sandstone over 20 ft thick [6429 7924]. Some 950 yd S. of spot-height 1511, the sandstone is overlain successively by 1 ft of shaly nodular mudstone, 1 ft of grey calcareous sandstone and 4 ft of grey micaceous mudstone. A further 320 yd downstream, a flaggy, fine-grained sandstone is underlain by calcareous sandstone said by Miller to contain *Chaetetes sp.*

South of the Antonstown Fault, in an unnamed watercourse flowing from the northern end of Kennel Crags [638 785], approximately 150 ft of strata crop out between the base of the group and the crags. Exposure is limited to a few sections of interbedded, fine-grained, calcareous sandstone and shaly micaceous and carbonaceous mudstone. Miller, in the original survey, noted a thin limestone [6377 7849] near the base, but it was not visible at the time of resurvey. About 12 ft of thin-bedded, fine-grained, calcareous sandstone are exposed [6386 7865] at a horizon 40 ft below the sandstone forming Kennel Crags. The latter is medium- to coarse-grained grey or dull white, quartzo-feldspathic, locally iron-speckled [6400 7846] and probably not less than 30 ft thick.

No sections are visible in the overlying 60 ft or so of strata, though near the top of this sequence the presence of a thin limestone is inferred from a line of sinks ranging along the base of Flush Crags. These crags [6440 7818] are formed by a lower 20-ft sandstone, separated by 12 ft of argillaceous measures from an upper 35-ft sandstone. Both are well-bedded, grey, medium- to coarse-grained, with locally false- or gnarled-bedding. The upper sandstone is friable at outcrop and is overlain at the south-eastern end of the crags [6475 7783] by a grey fine-grained siliceous sandstone.

In Padda Burn [6433 7884] near the Antonstown Fault, hardened and slickensided, massive, coarse-grained, quartzitic sandstone is exposed. Further sections in flaggy quartzitic sandstone are seen within the next 100 yd downstream. From there to the confluence [6485 7850] with an unnamed burn, isolated exposures of shales, mudstones and flaggy calcareous sandstones occur. At the confluence 15 ft of grey and dull white, massive false-bedded sandstone are faulted both to north and west. Some 150 yd below the confluence the stream is paved by rusty-brown weathering, tessellated, argillaceous limestone containing black elongate pellets or blebs of carbonaceous material. A coal, said to be a foot thick, crops out [6515 7797] in Padda Burn immediately below Davison's Crags.

The following section is exposed in Padda Burn [6528 7774], 500 yd N.N.W. of the Churnsike–Paddaburn road:

	ft
Shale, grey	2
Sandstone, massive grey fine-grained	6
Shale, grey micaceous and carbonaceous	1½
Shale, as above; fine sandstone bands	1½
Shale, coaly	½
Shale, carbonaceous and micaceous	1
Sandstone, grey fine-grained; plant fragments	1
Shale, grey; sandstone band ..	1½
Sandstone, fine-grained; plant fragments	1
Shale, grey; plant fragments at top	5
Sandstone, calcareous	3

Other isolated exposures along the burn consist mainly of flaggy or well-bedded, fine- to medium-grained sandstone. At Davison's Crags [6526 7795], 10 ft of flaggy medium- to coarse-grained sandstone are succeeded by about 20 ft of unexposed measures which are assumed to include a thin limestone on the evidence of sink holes. They are overlain, in turn, by a massive false-bedded sandstone. The next bed exposed in upward succession is a sandstone which lies some 60 ft above the sandstone of Davison's Crags. It is the most massive sandstone in the area and forms the bold escarpment of Paddaburn Crags, which is continued in a south-east direction to form Whaup Crags and Johnny's Crags north-west of Churnsike Lodge.

At Paddaburn Crags it is a locally false-bedded, yellow and grey, fine- to medium-grained rock with strong north-westerly jointing. Flaggy and more shaly, micaceous, locally carbonaceous bands or lenses are present, especially in the uppermost 15 ft. At Johnny's Crags [6600 7772], the rock is predominantly thinly false-bedded with a few lenticles of shale. An exposure [6600 7728], 520 yd W.N.W. of Churnsike Lodge, shows 4 ft of medium- to coarse-grained thinly false-bedded siliceous sandstone.

About 30 ft of measures, indifferently exposed at the head of Blind Sike [6579 7839], separate the sandstone of Paddaburn Crags from that of Cow Crags; they comprise alternations of mudstone and shale with bands of calcareous sandstone, a coal said to be 9 in thick and a thin bed of impure limestone. Cow Crags [6572 7846] are formed of a massive white false-bedded fine-grained sandstone with strong north-westerly joints. It is seen again [6625 7780], 750 yd N. by W. of Churnsike Lodge.

The positions of the massive sandstones at Swallow Crags, Lowe Bush, Weasel Crags and Stripe Pike are uncertain because of the intensity of faulting in the area, but they are probably related to the sandstones described above. The sandstone at Swallow Crags [6500 7917] is 25 ft thick and is fine- to medium-grained, false-bedded and massive, with occasional thinner, more flaggy bands. The rock at Lowe Bush [6533 7927] is grey, flaggy and fine-grained; it is probably over 30 ft thick and forms a wide dip-slope to the east (Stripe Rigg). Weasel Crags [6496 7933] are formed by 20 ft of thin-bedded, fine-grained sandstone separated by 30 to 40 ft of unexposed strata from the thin-bedded fine-grained sandstone of Stripe Pike [6490 7952]. All these sandstones appear to thin southwards: their outcrops are obscured by the wide alluvial flats of the River Irthing, and south of the river there are no solid rock features.

The area east of a line from Churnsike Lodge to the confluence of Greenmeath and Stripe sikes, and west of the outcrop of the Seven Linns Coal, is drift-covered except in the lower part of Black Cleugh, in Clock's Cleugh and at one or two other isolated localities. It is, nevertheless, possible to calculate that the strata between the sandstone forming Cow Crags, 950 yd S.S.E. of Lowe Bush, and the Seven Linns Coal range in thickness from less than 1000 ft in the south to 2000 ft in the north.

Small isolated sections in Blind Sike, north of Johnny's Crags, consist of fine-grained siliceous sandstone. Grey shale, locally nodular, and mudstone occupy a position 80 to 100 ft above the sandstone at Cow Crags. About a quarter of a mile N.N.E. of Johnny's Crags, the following section in the sike [6596 7832] is seen.

	ft
Shale, grey micaceous	1
Coal	¼
Shale, grey micaceous and carbonaceous	3
Sandstone, shaly micaceous and carbonaceous	1

On the north bank [6641 7837], 490 yd downstream, over 5 ft of massive, fine-grained, siliceous sandstone are exposed.

Whitehill Moor. In the Irthing valley, half a mile N. of Whitehill Farm [6814 7834], a coal said to be 16 in thick was worked from a series of small pits. Its position relative to the Seven Linns Coal suggests that it might be one of the Clock's Cleugh coals (p. 139).

In the bed of the Irthing at Whitehill Farm [6804 7747] two thin argillaceous limestones make tessellated pavements inclined gently to the south-east. They may be correlatives of the limestones exposed in the Chirdon Burn west of Seven Linns (p. 139), but the intervention of a small north–south fault between the limestones and the coal at Whitehill and the increase in thickness of strata northwards make this correlation uncertain.

In Coal Burn, over three-quarters of a mile N.E. of Whitehill Farm, barren, dark grey, carbonaceous micaceous mudstone, shale and calcareous sandstone form isolated exposures. A coal, said to be 8 in thick, and overlain by about 10 ft of carbonaceous shale, crops out [6873 7767] on Whitehill Moor, 820 yd E.N.E. of Whitehill Farm, and has been worked on a small scale from shallow shafts and an adit. Another coal, said to be 6 in thick, and underlain by carbonaceous shale, was formerly seen [6934 7768] in Coal Burn, 1450 yd E.N.E. of Whitehill Farm. In Coal Burn [6949 7788], 850 yd north of the confluence with Thross Burn, the following section occurs at a small waterfall:

	ft
Sandstone, calcareous fine-grained thin-bedded; crinoid columnals	4
Mudstone, calcareous micaceous	18
Sandstone, calcareous fine-grained thin-bedded; crinoid columnals	3
Shale, carbonaceous; ironstone nodules	3

A further 450 to 500 yd upstream, at the eastern margin of the district, the following section is visible:

	ft
Mudstone, shaly micaceous; becoming progressively more barren upward; scattered brachiopods and worm casts	15
Limestone, argillaceous thinly bedded; more massive upward [6975 7825]	5
Not exposed (probably shale)	2
Limestone, argillaceous; massive at top, thin-bedded below	12
Shale, grey	—

The limestone in this section may be the correlative of the Spy Hole Limestone seen in the River Irthing to the south. D.A.C.M.

CHIRDON BURN CATCHMENT

North of the Antonstown Fault. An extensive outcrop of sandstone forms the greater part of the high ground extending from Black Knowe to the area south of The Knares. It is cut off on the north by the Black Knowe Fault which extends along Birkygrain and south of Humble Hill, while further faulting in the area south-west of The Knares extends the outcrop along the valley sides on the east of the higher reaches of Pike Burn. The sandstone cropping out along the Antonstown Fault in Padda Burn and east of Pike Burn is probably the same bed. Stratigraphically it would appear to lie about 300 ft above the Maggot's Pike Limestone, but direct evidence for this is not available. The sandstone is probably more than 200 ft thick with a 40-ft shaly bed 60 ft from the base. At Pikeburn Crags [6358 7984] the rock is predominantly massive, medium-grained and variably coloured, with scattered flaggy, micaceous, carbonaceous bands.

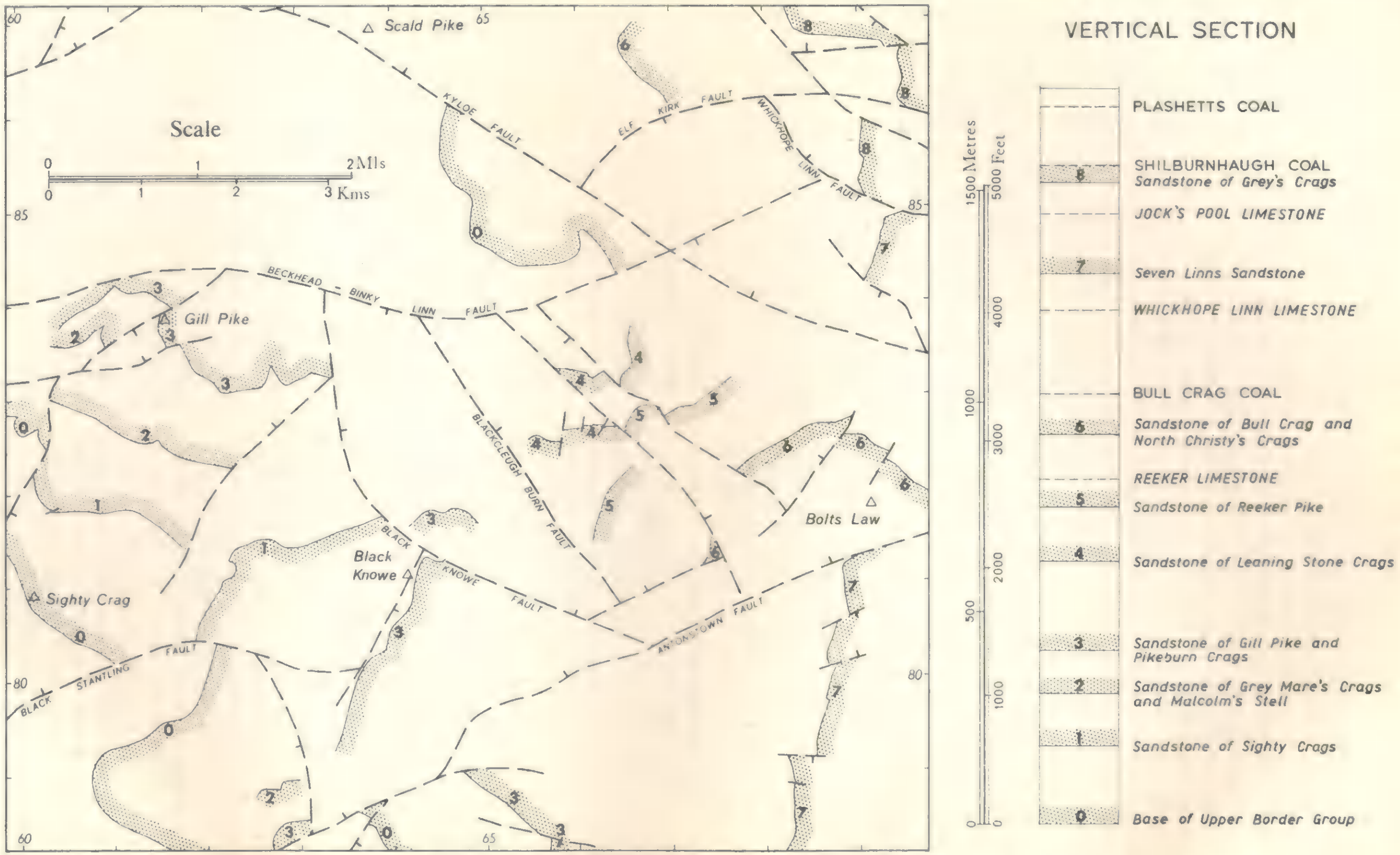


FIG. 26. *Sketch-map showing outcrops of selected horizons in the Upper Border Group in the north-eastern part of the district*

At Ox Crags [6405 8044] a 12-ft scarp of massive, fine- to medium-grained, loosely cemented sandstone with irregularly contorted bedding terminates an extensive dip slope of bare rock with a very gentle easterly dip. A similar sandstone, 120 yd S. of Ox Crags, shows small multi-directional iron ribbing, giving the rock a fretted appearance. The face of a quarry [6495 7982] south-east of Barren Crags consists of 25 ft of nearly horizontal, predominantly fine-grained sandstone, bedded in units 3 to 12 in thick, more massive at the base, and only locally false-bedded. Part of the face, about 20 yd wide and 12 ft high, shows alteration to almost incoherent, iron-enriched, reddish brown sandstone. The sandstone makes a wide dip slope east of Black Knowe and The Knares, where numerous sections in the upper part of the bed can be seen.

In the area forming the lower part of Birky Grain, several faults come together, the largest being the Black Knowe Fault which joins the Antonstown Fault at Craggy Shaw [6677 8032]. In consequence, a large part of the sequence overlying the sandstone referred to above is not represented in this area, but these beds are represented farther north around Reeker Sike.

The upward continuation of the sequence in the Birky Grain area is exposed discontinuously in Black Cleugh between the headwaters and the Antonstown Fault. Two beds of fine-grained flaggy sandstone 15 and 20 ft thick separated by 50 ft of unexposed strata crop out on the moor [6650 8137] west of Black Cleugh. Further thin bands of calcareous or siliceous predominantly fine-grained flaggy sandstone are seen in the cleugh itself, a few yards upstream from the following section:

	ft
WHICKHOPENICK SIKE COAL	½
Fireclay	½
Shale, micaceous carbonaceous	12
Shale, calcareous; impure muddy limestone bands [6686 8135]	6
Shale	2

Between this locality and the Black Cleugh Fault [6700 8100] the measures are obscured, though they are probably a repetition of part of the following sequence (loc. 80a) which crops out south of the fault:

	ft
Sandstone, flaggy fine-grained; interbedded with calcareous shaly mudstone	2
Shale, silty; occasional small ironstone nodules [6725 8070]; *Fenestella sp., Dielasma sp., Productus garwoodi, Stenoscisma isorhyncha, Euphemites sp., Acanthopecten sp., Aviculopecten sp., Edmondia* cf. *sulcata, Leiopteria* cf. *divisa, Palaeoneilo* cf. *luciniformis, Sanguinolites* cf. *clavatus, Schizodus sp.*	8
Sandstone, creamy grey rusty-weathering; predominantly well-bedded fine-grained siliceous (sandstone of North Christy's Crags)	25
Not exposed	18
Shale, grey micaceous carbonaceous barren	20
Mudstone and shale (poorly exposed)	26
Sandstone, calcareous flaggy; occasional plant fragments	10
Shale, grey barren micaceous	11
Sandstone, calcareous	1
Shale, grey	2
Mudstone, grey micaceous carbonaceous	1
Shale	4
Mudstone, sandy	1
Shale	8
Sandstone, flaggy	10 to 12
Not exposed	24
Sandstone, flaggy	10
Shale, coaly at base	8
CHANNELBUSH COAL [6716 8086]	1
Mudstone and shale, interbedded	24
Mudstone; occasional shale bands	8
Sandstone, calcareous	1
Shale; thin sandstone bands especially at base	25
CHANNELBUSH LIMESTONE	
Limestone, dun-coloured muddy argillaceous; *Lithostrotion sp., Buxtonia sp. nov., Semiplanus sp. nov.*	3
Shale; thin flaggy limestone bands, containing trepostomatous bryozoa, *Punctospirifer scabricosta, Stenoscisma isorhyncha, Retispira sp., Hypergonia sp.*, gastropods indet., *Leiopteria divisa* [6714 8092]	4
Shale; mudstone bands	6
Not exposed	4
Shale and flaggy sandstone	2
Not exposed	20
Sandstone, calcareous	10
Shale, grey sandy micaceous and carbonaceous	2

BLACK CLEUGH LIMESTONE	ft
Limestone, argillaceous [6706 8096]	8
Shale	1
Not exposed	12
Shale and thin calcareous flaggy mudstones, interbedded	6
Not exposed	30
Sandstone, mainly massive medium- to coarse-grained; locally flaggy	20+

Higher measures are only indifferently exposed between Black Cleugh, Rushy Knowe [6778 8169] and Bolts Law [6910 8183]. On the moor [6955 8155], 500 yd S.E. of Bolts Law, a line of sink holes marks the outcrop of the Rushy Knowe Limestone. An overlying massive, fine-grained and locally false-bedded sandstone makes a craggy scarp. The beds poorly exposed in the headwaters of Clock's Cleugh are dominantly argillaceous, but they include three thin coals which have been worked on a limited scale at outcrop. The lowest coal, said to be 12 in thick, is underlain by a thin, locally calcareous sandstone, and forms a roughly semi-circular outcrop on the north side of the Antonstown Fault. The coal was worked a little at outcrop [6791 8137] 1400 yd W.S.W. of Bolts Law. An overlying sequence of south-eastward dipping calcareous mudstones and shales, with ironstone nodules, and sandstone beds are seen sporadically in streams 750 yd S.W. and 550 yd S.S.W. of Bolts Law. At the confluence [6860 8138] of the streams the following section is visible:

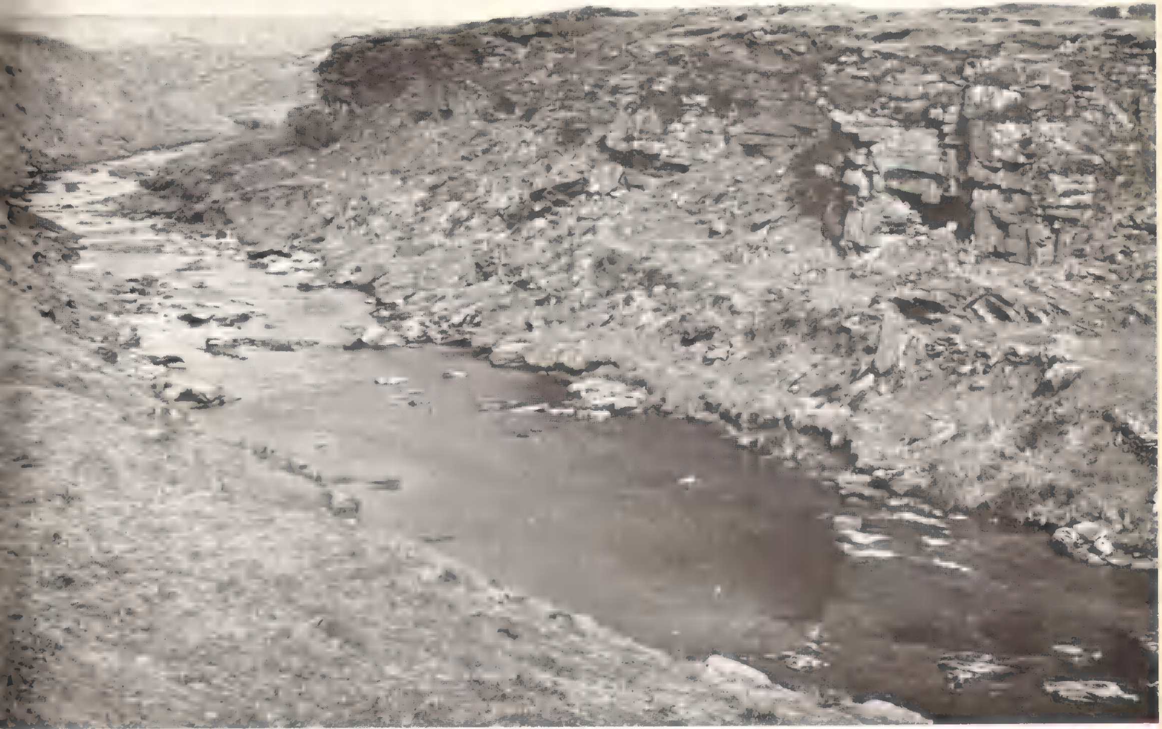
	ft
Shale, silty dark grey highly micaceous; ironstone nodules ..	3
Sandstone, thin-bedded ferruginous	1
Shale and mudstone (poorly exposed)	8
Shale, grey; ironstone nodules; locally coaly	3
Sandstone; dark shale partings ..	2
Sandstone, flaggy fine-grained ..	1

The Whickhope Linn Limestone should be at about this horizon, although it is not known to crop out in this area. Two thin coals farther downstream, and crossing the streams 750 yd S.W. and 600 S.S.W. of Bolts Law respectively, were recorded by Miller in the original survey, but are no longer visible. They probably lie some 600 ft above the horizon of the sandstone of North Christy's Crags and are considered to be the correlatives of the Clock's Cleugh Coals (p. 139). Higher beds incropping against the Antonstown Fault and representing the highest beds of the Upper Border Group in this area are not exposed.

South of the Antonstown Fault. In Black Cleugh, which runs approximately along the strike, exposures are poor. They include 6 ft of siliceous sandstone overlying shales dipping steeply northwards against a fault about 200 yd N. of the confluence with Chirdon Burn. An exposure [6742 8028], 450 yd N. of the confluence of Black Cleugh and Chirdon Burn, shows 10 ft of calcareous mudstone interlaminated with dark grey slickensided shale, while just below [6741 8045] the confluence of Black Cleugh and Channelbush Sike are two thin impure limestones separated by approximately 30 ft of strata. The lower limestone, here named the Black Cleugh Limestone (loc. 80b), contains *Lepidostrobus fimbriatus* Kidston, *Buxtonia sp. nov.*, *Productus garwoodi*, *Soleniscus sp.*, *Aviculopecten sp.* and an indeterminate coiled nautiloid. This fauna suggests a horizon low in the Upper Border Group. The limestone is immediately overlain by 3 in of coal and mudstone, above which are 25 ft of grey carbonaceous micaceous shales. Above these is the upper of the two thin limestones, the Channelbush Limestone. It is only imperfectly seen and is separated from the overlying Channelbush Coal by 30 to 35 ft of unexposed strata. The coal, said to be up to 1 ft thick, was worked at outcrop for a short distance along the south bank of Channelbush Sike [6755 8059]. The coal is succeeded by dark grey barren shale with ironstone nodules. The strata in this area of Black Cleugh are inferred to be approximately 700 ft below the Seven Linns Coal.

Shales, siltstones, mudstones and muddy calcareous sandstones are indifferently exposed in Clock's Cleugh west of Hope House. Most of the shales and mudstones are dark grey, micaceous and carbonaceous with ironstone nodules and bands, and are locally irregularly bedded. These beds are underlain by over 10 ft of massive medium-grained siliceous sandstone which is exposed at Gun Crags [6815 8067] on the west side of Clock's Cleugh.

Younger strata exposed north of the Clock's Cleugh Fault and south of the Antonstown



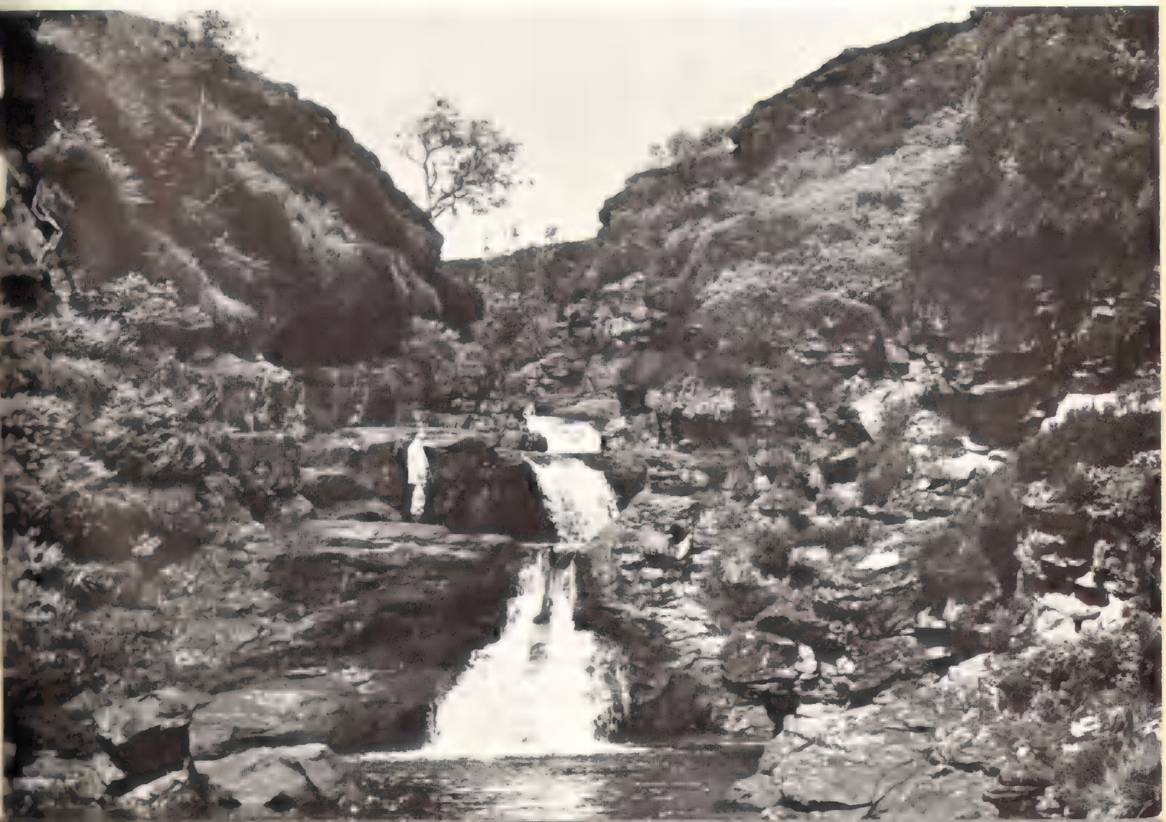
(L 439)

A. The Spy Rigg Sandstone; Sundayburn Linn, River Irthing, looking north-eastwards

PLATE VI

B. The Seven Linns Sandstone at Seven Linns

(L 419)



Fault include the Upper and Lower Clock's Cleugh coals which are 18 in and 12 to 16 in thick respectively. They are exposed on the southern side of Clock's Cleugh [6843 8079], where they are overlain by shale. The coals are separated by 37 ft of strata mostly unexposed, but the shales forming the roof of the lower coal are grey, micaceous and silty with interbedded fine sandstone laminae, and contain plant fragments. South of the Hope House Fault these coals are believed to crop out in Chirdon Burn near the confluence with Clock's Cleugh, although they are not exposed. The coals are separated from the Seven Linns Coal by about 150 ft of strata of which only isolated exposures of calcareous sandstone and shale, usually ferruginous, are seen. They include the Hope House Limestone which, as measured by Miller in the bed of Chirdon Burn [6847 8020], is 8 ft thick and is greenish and gritty, with plant fragments and shells: it rests on 2 ft of carbonaceous shale and is overlain by 2 ft of greenish shaly sandstone. No further exposures are visible in Chirdon Burn down to Seven Linns.

The Seven Linns Coal has an average thickness of 18 in and can be mapped continuously at the base of the Seven Linns Sandstone as far south as Whitehill Farm. Locally, as at Chirdon Burn, it is separated from the base of the sandstone by up to 28 in of shale and shaly sandstone.

The Seven Linns Sandstone is a predominantly massive, fine- to medium-grained rock locally flaggy and false-bedded especially at the top and base. It is strongly jointed in a north-westerly direction. Exposures extend southward from Clock's Crags [6889 8070] to Seven Linns where the sandstone is 80 to 90 ft thick. It becomes progressively thinner southwards as it is traced through Little Samuel's [6867 7966] and Muckle Samuel's crags. At the last locality [6835 7890] over 30 ft of massive, wedge-bedded, fine-grained, predominantly siliceous sandstone are exposed. Still farther south the sandstone is last seen crossing the River Irthing at Whitehill Farm.

In Chirdon Burn, below Seven Linns, a discontinuous section extends upwards for about 500 ft from the Seven Linns Sandstone to include Chirdon Nos. 1 and 2 coals and Chirdon Nos. 1 and 2 limestones. It is detailed in Appendix I, p. 280.

Chirdon No. 1 Limestone also crops out [6966 8021; loc. 81] 315 yd N.N.E. from spot height 1085 on Coom Rigg, and contains the following fauna, suggesting a position in the lower half of the Upper Border Group: *Diphyphyllum sp.*, *Fenestella frutex*, *Buxtonia sp. nov.*, *Echinoconchus* cf. *elegans*, smooth spiriferids indet., *Semiplanus sp. nov.*, *Spirifer sp.*, *Stenoscisma isorhyncha* and a cochliodont fish-tooth.

Chirdon Nos. 1 and 2 limestones are tentatively equated with the Lower and Upper Millerhill limestones cropping out in the River Irthing, 2½ miles to the south (p. 106), because of their positions relative to the Spy Rigg Sandstone, although there is little in common between the faunas from the two areas.

North of the Chirdon Burn exposures are isolated and only the thicker sandstone horizons can be traced for any distance.

D.A.C.M.

WHICKHOPE BURN CATCHMENT

Back Burn (loc. 82). The headwaters of the Back Burn cross silty shales with thin sandstone partings [610 817] and farther downstream successively younger measures are exposed, starting with thin-bedded, ripple-marked sandstone [614 817] which lacks the irregularly contorted bedding seen at the same horizon in Sighty Crags farther west. North of Horse Head, the burn runs through the following incompletely exposed section:

	ft
Limestone, argillaceous [6182 8177]	about 2
Not exposed	about 10
Shale, grey calcareous	½
Coal	¼
Shale, grey partly silty; plant fragments; poorly exposed	about 20
Coal	¼
Shale, grey silty; thin, fine-grained sandstone bands	6
Not exposed	3
Limestone, argillaceous; large septarian nodules	4
Not exposed	5
Shale, grey silty	2
Not exposed	about 20

	ft
Shale, silty micaceous; thin sandstone bands	3
Sandstone, fine-grained	¼
Shale, grey	2
Sandstone, thin-bedded fine-grained partly calcareous; silty shale partings; crinoid columnals, *Fenestella sp.* and *Sanguinolites*?	8
Not exposed	about 3
Shale, silty	1¼
Coal and coaly shale	½
Seatearth-mudstone	about 1
Sandstone, thin-bedded fine-grained	4
Shale, grey partly silty	about 4
Not exposed	about 2
Limestone, fine-grained argillaceous [6161 8171]	1

The next exposures downstream from this locality lie on the upthrow side of the Horse Head Fault and are of uncertain stratigraphical position (see below). Consequently, the next beds seen in upward succession are those forming a series of faulted sections in Shaly Sike, the southernmost left-bank tributary of Back Burn. The headwaters of this sike are crossed by an east-north-easterly fault [6164 8204] which probably throws down to the south. North of it are disconnected exposures of sandstone, including 4 ft of hard, thin-bedded, calcareous rock adjacent to the fault. South of the fault 5 ft of sandy, fossiliferous limestone in courses up to 4 in thick, with thin, grey shale partings, rest on about 5 ft of grey silty mudstone. From the limestone the following have been collected: *Fenestella sp.*, trepostomatous bryozoans; *Punctospirifer scabricosta*, *Retispira sp.*, *Straparollus sp.*, *Aviculopecten* cf. *plicatus*, *Leiopteria divisa* and orthocone nautiloid. Some 70 yd farther downstream [6172 8201] is another fault which has a north-north-easterly trend. On the western, upthrow side 5 ft of hard, thin-bedded, calcareous sandstone dip at 16° to the north-north-east. East of the fault are about 25 ft of thin-bedded, fine-grained sandstone with shale partings and with a 3-ft bed of carbonaceous shale intercalated 5 ft from the top.

Still farther downstream [6181 8195] is the following section:

	ft
Coal and coaly shale	½
Seatearth-mudstone	½
Mudstone, grey; ostracods; roots at top	3
Mudstone, silty	1
Mudstone, calcareous; silty in part; *Spirorbis sp.*, *Linoproductus sp.*, *Soleniscus*?, turreted gastropod indet., *Myalina pernoides*, *Pteronites angustatus*, *Sanguinolites* cf. *variabilis*, *Schizodus sp.* and ostracods	¼
Mudstone, grey shaly; *Lingula* aff. *squamiformis*, *Linoproductus sp.*, *Pteronites angustatus* and ostracods	4

Continuing down the sike from this exposure are about 70 ft of indifferently exposed shaly strata. The highest beds seen are 2 ft of carbonaceous shale overlain by 6 ft of grey shales with shell and plant fragments [6192 8197].

Exposures in a 500-yd stretch of Back Burn near its confluence with Shaly Sike are considered (because of discordance of dip and strike) to lie on the south-eastern, upthrow side of the Horse Head Fault, where they are folded and form isolated sections which cannot be related stratigraphically to each other or to sections elsewhere. The southernmost section forms an anticline in which the highest strata, dipping at 56° to west-north-west on the left bank [6204 8191], consist of two 3-ft beds of brown-weathering false-bedded, fine-grained calcareous fossiliferous sandstone separated by 2 ft of grey shales. The sandstones contain *Punctospirifer scabricosta*, *Hypergonia sp.*, *Leiopteria divisa*, *Myalina sp.* and carbonized plants. They are probably only a few feet above the highest bed of the following section, which forms a sharp-crested anticline trending north-north-east with dips of 50°, and which is exposed on both banks about 20 yd downstream:

	ft
Shale, grey; silty in part	10
Sandstone, fine-grained; a shale parting	2
Shale, silty micaceous; thin shaly sandstone partings; blue in lowest 2 ft, brown above	8
Sandstone, flaggy fine-grained; micaceous-carbonaceous films and thin shale partings	3
Shale, grey; silty at top, dark at base	1
Coal	½
Fireclay-mudstone, grey	¾

	ft
Shale, carbonaceous; coal streaks	½
Fireclay-mudstone, grey	½
Not exposed .. probably about	5
Shale, grey silty	1
Limestone, argillaceous; *Linoproductus sp.*, *Edmondia sp.* and *Myalina pernoides*	1½ in —
Shale, grey; calcareous at top	1¼

Farther downstream [6219 8207], 130 yd N.E. of the Shaly Sike confluence, three exposures combine to give the following section:

	ft
Limestone, sandy brown-weathering fine-grained; ill-defined false-bedding; crinoid columnals, *Fenestella sp.*, *Buxtonia sp. nov.*, *Linoproductus sp.*, *Punctospirifer scabricosta* and *Aviculopecten spp.*	5
Sandstone, flaggy, and shales; poorly exposed	15
Shale, grey; some coal debris; poorly exposed .. about	8
Shale, grey calcareous; thin (up to 1 in) limestones containing *Edmondia* cf. *sulcata*, *Leiopteria sp.*, *Myalina pernoides* and *Pteronites sp.*	2½

The lowest bed has narrow calcite veins striking at 100°.

The last of the exposures on the south-eastern, upthrow side of the Horse Head Fault is about 130 yd farther down Back Burn [6223 8217], where a shallow syncline trending east-south-east and plunging gently in the same direction is formed by the following strata:

	ft
Shale, grey	½
Coal	¼
Shale, grey; roots; carbonaceous at top, silty at base	1
Sandstone, thin-bedded fine-grained; micaceous-carbonaceous film partings; shaly and rooty at top	7
Shale, brown silty	2
Shale, carbonaceous	¼
Clay, grey (?weathered seatearth-mudstone)	4
Sandstone, flaggy ripple-marked fine-grained micaceous; carbonaceous-micaceous film partings	4½

On the downthrow side of Horse Head Fault, farther down Back Burn, at and south of the confluence with an unnamed tributary sike [6225 8236], fine-grained, thin-bedded sandstone is exposed. The sandstone also floors the tributary sike for nearly 200 yd, and can be traced westwards across the moor (where it forms Grey Mare's Crags) to Yett Burn. Higher beds crop out [6225 8243] 35 yd S. of the confluence with Black Jack Sike, where 1 ft of carbonaceous shale overlies 1 ft of grey, silty fireclay-mudstone. At the confluence, and stratigraphically a few feet higher, thin-bedded, fine-grained sandstone with a few shell fragments is overlain by dark calcareous shale with ostracods and coal streaks. This coaly ostracod-shale, which is poorly exposed and of indeterminate thickness, is correlated with the carbonaceous limestone containing ostracods in Yett Burn (p. 153).

Strata probably about 20 ft higher are seen in Black Jack Sike [6218 8248], 85 yd W. of Back Burn, where the section is

	ft
Sandstone, brown-weathering fine-grained; micaceous-carbonaceous film partings	5
Shale, dark grey calcareous; *Aviculopecten* cf. *plicatus*, *Naiadites crassus*, *Sanguinolites sp.* and ostracods	3
Limestone, dark argillaceous	1½ to 2
Shale, dark grey; plants and coaly streaks	1
Not exposed .. about	2
Sandstone, massive fine-grained	2

The lowest sandstone of this section is strongly jointed along trends of 85° and 175°. The limestone and shales are cut by a north-north-westerly calcite vein up to ¾ in wide containing scattered crystals of brown sphalerite, and hading west-south-west at about 45°.

The topmost sandstone of the above section is seen intermittently farther upstream in Black Jack Sike, and can be followed north-eastwards in crags on the left bank of Back Burn. It is probably equivalent to, or possibly slightly lower than, the sandstone at the base of the following section in the burn:

	ft
Sandstone, fine-grained; partly thin-bedded, partly false-bedded; lowest 9 in is ochreous; *Fenestella sp.*, *Aviculopecten* cf. *plicatus*, *Myalina sp.*, *Polidevcia attenuata* and orthocone nautiloid [gorge at 625 827]	50

	ft
Shale, silty; very poorly exposed	about 2
Shale, carbonaceous	¼
Shale, grey and fawn; rootlets at top; becoming silty with a few sandy partings below	4
Sandstone, strongly false-bedded fine-grained; forming cascade [6242 8260]	5

At the northern end of the gorge, the 50-ft sandstone of the section terminates against a fault marked by a waterfall and there are no further exposures downstream for 400 yd. The beds which next appear, at Broomy Linn, are probably about 100 ft higher in the succession. They are seen partly in the stream and partly in a cliff on the east bank [6275 8321] as follows:

	ft
Sandstone, false-bedded thin-bedded fine-grained	about 12
Shale, dark grey; carbonaceous at some horizons	5
Interbedded shaly flaggy sandstones and silty shales	20
Not exposed	about 25
Shale, grey; plant fragments and carbonaceous streaks	1½
Coal, shaly, and coaly shale	½
Shale, grey; carbonaceous at top	1
Not exposed	about 2
Sandstone, flaggy fine-grained calcareous micaceous; sandy calcareous shale partings; worm tubes	6
Sandstone, massive false-bedded fine-grained; intermittently exposed	about 40

The sandstone at the top of this section is the highest bed seen in Back Burn. It forms the lower part of the sandstone of Gill Pike and is further exposed in Woody Sike, a left bank tributary, where it contains shale partings and a fine-grained calcareous bed [6207 8320] which has yielded *Punctospirifer scabricosta*, *Sanguinolites sp.* and an orthocone nautiloid.

Horse Head to The Rigg. Low crags [6234 8128] to the east of Horse Head are formed by massive, fine-grained sandstone dipping gently to north-west off the crest of the east-north-easterly Humble Hill Anticline.

Scattered exposures farther north consist mainly of sandstones and shales, with a 6-in coal [6262 8206] in a right bank tributary of Back Burn, and 9 in of grey argillaceous limestone [6367 8359] on The Rigg.

Humble Burn. South-west of the Black Knowe Fault grey shales are intermittently exposed in the head-waters of Humble Burn and downstream [6350 8204] the burn is floored by massive sandstone. North-east of the fault, the burn flows for about 400 yd over false-bedded sandstone, which is estimated to be about 20 ft thick and which is traversed by strong joints, striking between 340° and 350°. At the north end of this stretch the sandstone is overlain by the following sequence:

	ft
Sandstone, brown thick-bedded fine-grained [6375 8289]	6
Shale, grey badly exposed; poorly preserved small bivalves	about 10
Sandstone, grey (brown-weathering) fine-grained calcareous	1½
Limestone, grey argillaceous; a few ostracods	1½
Not exposed	about 5
Mudstone, blue (ochreous-weathering) silty micaceous; some sandy partings	5
Not exposed	3
Sandstone, bluish green slightly calcareous fine-grained; small oval concretions; a few plant fragments	3

The north-north-westerly dip in this section is generally 14°, but it is 50° at a west-south-westerly striking monocline which crosses the outcrop of the limestone. This monocline also appears in sandstones exposed in sikes 250 and 570 yd to the east-north-east.

Humble Hill and Wedder Lairs. The sandstone forming the summit crags of Humble Hill [644 817] consists of a lower 15-ft post separated from an upper 10-ft post by a few feet of unexposed softer strata. The sandstone is thick-bedded, fine-grained and quartzitic, and dips southward at about 10° on the southern limb of the east-north-easterly Humble Hill Anticline, the axis of which passes about 200 yd N. of the summit.

North of the axis dips vary from 4° to 10° in a series of sandstones, totalling some 150 ft in thickness, cropping out on the hillside. On the southern higher part of the hill two prominent craggy escarpments, Windy Crags [6383 8216 to 6497 8233] and Burnt Crags [6355 8230 to 6487 8253], each three-quarters of a mile long, are formed of 25- to 30-ft cliffs of massive, fine-grained, quartzitic, locally false-bedded sandstone.

The lowest strata in this area are exposed at the core of a subsidiary anticline at the head of Gulley Sike [6465 8270] as follows:

		ft
Sandstone, fine-grained; heavily jointed; veined by calcite		about 2
Shale, grey (debris only seen)		1
Coal, shaly	1 in	—
Fireclay-mudstone, pale grey		1¼
Sandstone, fine-grained, ferruginous micaceous; well-jointed		5
Shale, grey; a coaly horizon (poorly exposed)		about 4
Not exposed		about 12
Limestone, sandy ochreous; narrow veins of calcite with aragonite and a black hydrocarbon mineral		about 3
Shale, brown calcareous; thin hard partings; *Sanguinolites sp.* and ostracods		1½
Shale, carbonaceous		¼
Mudstone, grey-brown silty		¾
Shale, grey-brown calcareous; ostracods		4
Not exposed		about 3
Sandstone, brown fine-grained argillaceous micaceous; a few roots		1
Shale, grey silty micaceous		½

Blackcleugh Burn (loc. 83). A long section interrupted by three faults can be made out in the upper part of Blackcleugh Burn. The higher strata are exposed in the eastern headwaters [6526 8236 to 6523 8261] which are not shown on the one-inch map: the remainder are in the main stream [6522 8264 to 6519 8299]. The section is given in detail in Appendix I, p. 275.

There are no exposures in the middle reaches of the burn, but towards its confluence with Humble Burn a gorge is cut through about 35 ft of sandstone. This rock is mostly thin-bedded and fine-grained, with local thick-bedding and false-bedding, and with ferruginous specks. The top of this sandstone is about 120 ft below the base of the section mentioned above.

Binky Burn (loc. 84). Exposures in and east of Binky Burn near the confluence [6591 8389] with Humble Burn are discontinuous. Immediately south of the Beckhead–Binky Linn Fault [6606 8413] about 6 ft of flaggy and shaly fine-grained sandstone with a 9-in parting of grey slightly calcareous siltstone containing *Lingula sp.* are exposed in the burn. About 100 yd upstream are the following strata [6601 8408]:

		ft
Sandstone, grey (weathering brown) thin-bedded coarse-grained slightly calcareous; plant debris		2
Shale, grey partly calcareous; a 3-in calcareous siltstone		2
Coal	1 in	—
Fireclay-mudstone		¼
Coal		¼
Fireclay-shale		1
Shale, carbonaceous		2
Coal, shaly		¼
Fireclay-mudstone, grey		½
Sandstone, brown medium-bedded fine-grained; shaly partings towards top		about 12
Not exposed		between 3 ft and10
Shale, grey		about 2
Siltstone, grey (brown-weathering) calcareous		¾

The sandstone at the top of this section is the lowest part of a sandstone cropping out upstream over a distance of about 100 yd in small crags near the burn and in a little sike which enters from the east. The outcrop forms an eastward-plunging syncline which appears to be a localized fold on the downthrow side of the Beckhead–Binky Linn Fault.

Farther upstream, 85 yd N.E. of the confluence of Binky and Humble burns, is the following section [6596 8395] which is stratigraphically only a few feet below the section tabulated above:

	ft
Sandstone, thin-bedded fine-grained; very ferruginous in bottom foot	3
Shale, grey; sandy micaceous at top; a few plant fragments in the middle, shell debris near base	3¾
Limestone, grey; *Fenestella sp.*, trepostomes, *Buxtonia sp. nov.*, *Productus garwoodi*, *Aviculopecten sp.* and ostracods	¾
Shale, grey silty micaceous	1¼
Coal	½
Fireclay-mudstone, grey; carbonaceous at top	1⅔
Shale, grey rather silty	3½

A north-westerly fault cuts off this section to the west, and brings down 15 ft of thin-bedded, fine-grained, somewhat ferruginous sandstone.

Calcareous, fine-grained sandstone containing *Punctospirifer* fragments and crinoid columnals is exposed [6591 8388] at the confluence of Humble and Binky burns.

Somewhat lower strata are seen in Binky Burn at 100 to 320 yd upstream from the confluence as follows:

	ft
Sandstone, thin-bedded fine-grained micaceous ripple-marked; fragmentary carbonized plants on some bedding planes; calcareous with poorly preserved brachiopods and bivalves in lowest few inches	5
Coal 2 in	—
Fireclay-mudstone, grey	3½
Shale, grey silty rooty	3
Sandstone, flaggy irregularly bedded fine-grained; thin shale partings	6
Sandstone, thin-bedded fine-grained	6
Not exposed	about 2
Shale, grey silty micaceous slightly calcareous; thin calcareous sandstone partings; fragmentary plants	6
Not exposed	about 14
Shale, as above	15

Several beds of sandstone, and two thin coals are poorly exposed in the sike entering Binky Burn, 150 yd below the Humble Burn confluence. In the forest both north and south of the sike, and also to the east, prominent crags of fine-grained, thin- and false-bedded sandstones are the only strata visible and a number of north-westerly faults have been mapped.

In Binky Burn (loc. 84b), 800 to 1000 yd S. of the Humble Burn confluence, the following strata are exposed:

	ft
Sandstone, thin-bedded fine-grained [6615 8302]	6
Shale, grey	about 8
Shale, grey; silty in part; thin sandstone partings	6
Shales; silty partings; fireclay-mudstone near top	about 10
Sandstone, grey fine-grained calcareous	½
Mudstone, grey calcareous; crinoid columnals; *Linoproductus sp.*, *Edmondia* cf. *sulcata* and *Leiopteria*	1½
Limestone, dark grey argillaceous; shell debris	1
Shale, carbonaceous; thin coal partings	2
Shale, grey; fragmentary plants in top part; calcareous and irregular-bedded in middle; silty and poorly exposed in lower part	10
Sandstone, grey brown-weathering fine-grained calcareous and micaceous; a 4-in shaly parting near the middle	3½
Not exposed	about 5
Sandstone, blue (brown-weathering) hard fine-grained	1⅔
Shale, grey; poorly exposed	about 5
Sandstone, thin-bedded fine-grained; thin shaly partings; decalcified at top, '*Camarotoechia*' *sp.*, *Punctospirifer scabricosta* and *Pteronites angustatus*	3
Shale, grey silty micaceous	3
Sandstone, brown thin-bedded fine-grained micaceous; a median 20-in silty shale parting	5⅔
Mudstone, grey silty micaceous	2
Shale, carbonaceous	½
Coal	½
Shale, carbonaceous	¼
Fireclay-mudstone, grey; a few inches carbonaceous near top; ironstone nodules in lower part	4
Sandstone, hard grey brown-weathering fine-grained slightly calcareous; some roots	2½
Shale, some coal debris; poorly exposed	about 12
Sandstone, thick-bedded fine-grained; ferruginous specks; some false-bedding; a few thin shaly partings	30
Not exposed	about 15
Shale, grey rooty; some carbonaceous beds and thin coal partings	6
Sandstone, false- and thick-bedded fine-grained [6615 8320]	6

In and around the headwaters of Binky Burn, sandstones, between 10 and 20 ft thick, form several craggy escarpments. There are no exposures between the sandstones.

Little Whickhope Burn (south of the Kyloe Fault). Fine-grained sandstone, 30 to 40 ft thick, crops out at Reeker Pike and again 500 yd due east [6727 8288]. A few feet below it, in a sike [6720 8289] south of Byreshield Hill, is a 1-ft argillaceous limestone.

Above the sandstone are about 600 ft of

strata exposed in Little Whickhope Burn and its headwaters; the section is detailed in Appendix I (p. 291). The lowest strata, dipping at between 25° and 30° to the south-east in Reeker Sike (the east-north-easterly headwater on the south side of Reeker Pike), are dominantly argillaceous and include several beds of carbonaceous shales, a few thin coals, and two thin limestones. A 20-ft sandstone near the top of this sequence thickens locally to about 50 ft on the south-western side of the Reeker Pike Fault. Higher strata, in Little Whickhope Burn, consist mainly of sandstone and shale, in beds up to 50 ft thick, with a few thin coals. Only two fossiliferous beds occur in the uppermost 400 ft, though there may be others in some of the unexposed parts of the section. A 40-ft sandstone overlying an unnamed limestone, 107 ft below Christy's Walls Coal, reappears as a low rocky ridge in the forest [6686 8227], 650 yd S. of Reeker Pike, where it contains moulds of brachiopod shells. Another 40-ft sandstone, immediately overlying Christy's Walls Coal, is exposed at the confluence [6762 8278], half a mile E. of Reeker Pike and forms crags extending eastwards from Christy's Walls [6826 8298] to the Kyloe Fault [6911 8354].

Strata above the 600-ft section in Reeker Sike and Little Whickhope Burn crop out on the hillside south and east of the burn. The lowest, which lies about 50 ft above the Whickhopenick Sike Coal, is the sandstone forming Kyloe Crags, where it is exposed over a distance of 1500 yd; it is about 25 ft thick and is thin-bedded, partly false-bedded and fine-grained. Between it and the sandstone of Christy's Crags are some 275 ft of strata which are fragmentarily exposed at two localities. One is near the margin of the district, in Smales Burn [6966 8244], where a few feet of grey, brown-weathering calcareous sandstone with shell debris are seen. At the other, in Christy's Sike [6813 8258], below Christy's Crags, the section is as follows:

	ft
Shale, silty micaceous; calcareous bands	3
Not exposed	about 4
Limestone, grey argillaceous ..	1
Shale, grey, in alternations of calcareous shelly bands and non-calcareous bands with plant debris	6

The rocky escarpment of Christy's Crags can be followed for about 1½ miles. It is formed by sandstone, about 50 ft thick, which has been eroded along a soft parting giving rise to a stepped profile. Another sandstone, nearly 200 ft higher, forms the summit crags of Bolts Law [691 818], where it is massive, false-bedded and fine- to medium-grained. Only 12 ft are exposed, but the total thickness of this sandstone is probably about 20 ft. Its outcrop can be traced westwards, shifted by faulting, through Robin's Knowe [6855 8207], and another rocky escarpment [6815 8209] to the southern end of Christy's Crags where the Reeker Pike Fault brings it against the lower sandstone which forms the main length of the crags.

Little Whickhope Burn (between the Kyloe and Saughy faults). North of the Kyloe Fault the Little Whickhope Burn follows a winding north-easterly course through the following sequence:

		ft
Sandstone, hard fine-grained calcareous [6882 8363]		1
Shale, grey		1¼
Coal	1 in	—
Fireclay-shale, grey; carbonaceous at some levels; many plants and roots		1
Coal	10 in	¾
Fireclay-mudstone, grey		1
Shale, grey		2
Sandstone, thin-bedded fine-grained; shaly partings		5
Not exposed		about 27
Sandstone, thin-bedded fine-grained; shaly partings		15
Shale, grey silty; argillaceous sandstone partings (up to 2 in), micaceous in part; fragmentary plants		about 40
Sandstone, flaggy fine-grained ..		2
Shale, grey [6893 8375]		1

In a tributary sike, which enters from the south-east, about 40 ft of grey, apparently unfossiliferous shale are seen; they underlie the above section.

Farther downstream, where the course of the burn is north-westerly, exposures are discontinuous and consist mainly of shales. At one locality [6888 8390] about 15 ft of grey shales with a few fine-grained sandstone partings overlie 1 ft of well-bedded, sandy limestone with abundant grains of ferric oxide. In thin section (E 32779) the limestone is seen to consist predominantly of organic remains including foraminifera, crinoid columnals and bryozoa which are composed mainly of uniformly-extinguishing calcite. There is also carbonaceous matter, in part delicately replaced by hematite, which emphasizes cellular structures. Other clastic grains include angular quartz (0.2 to 0.4 mm) partly replaced by calcite, quartzite, microcline, perthite and composite quartz-orthoclase. The rock matrix is chiefly composed of coarsely crystalline interlocking calcite grains. A little secondary sulphide is present and there is also fine veining by secondary calcite. About 115 yd farther downstream is an exposure of 22 ft of grey micaceous mudstone with partings of slightly calcareous siltstone showing cone-in-cone structure.

Stratigraphically below the exposures just described is the following section (loc. 85a), which is seen in Little Whickhope Burn between Byreshield Grains confluence [6872 8403] and the Saughy Fault [6892 8431]:

	ft
Shale, grey micaceous; silty beds, ironstone nodules; plant fragments	about 25
Shale, grey; poorly exposed	about 10
Shale, grey; *Fenestella sp.*, *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Aviculopecten* cf. *plicatus* and ostracods	2
Limestone, argillaceous sandy; *Buxtonia sp.*, '*Camarotoechia*' *sp.*, *Semiplanus sp.*, *Spirifer* cf. *trigonalis* and *Edmondia* cf. *sulcata* ..	2½
Shale, grey; hard and calcareous in middle; *Lithostrotion sp.*, *Fenestella frutex*, *Penniretepora sp.*, *Buxtonia sp. nov.*, *Composita sp.*, *Linoproductus sp.*, *Spirifer sp.*, *Leiopteria sp.* and orthocone nautiloid ..	7½
Mudstone, grey silty; silty shale partings	2
Sandstone, grey fine-grained siliceous; coal pellets at base	1¼
Coal, with irregular eroded top 1 in to	⅓
Shale, grey; roots	½
Coal; irregular shale partings up to 1½ in thick	½
Shale, grey; plants and roots; carbonaceous at top	2
Coal .. .. ¾ in	—
Fireclay-mudstone, grey	⅔
Shale, grey slightly micaceous ..	3
Sandstone, fine-grained argillaceous slightly calcareous; crinoid columnals, '*Camarotoechia*' *sp.*, *Modiolus sp.*, *Myalina sp.* and plant fragments	¾
Shale, poorly exposed ..	about 5
?Fault, cutting out less than ..	10
Sandstone, massive fine-grained	about 30
Limestone, dark grey argillaceous; *Lithostrotion sp.* and *Semiplanus sp.*	7
Shale (not seen during resurvey); spiriferids, gastropods, ostracods and plant fragments	—

Two other exposures are worth mention in the ground between the Kyloe and Saughy faults. One is near the head of Saughy Sike [6939 8386] where 4 ft of grey shale overlie 1 ft of brown calcareous sandstone with crinoid columnals and *Spirifer* fragments. The other exposure is near the head of Kyloe Slack Sike [6914 8360].

	ft
Shale, brown silty	10
Sandstone, fine-grained decalcified; bryozoan and brachiopod fragments	1
Coal	¼
Shale, grey; fragmentary plants; carbonaceous in places	6
Shale, brown	about 10
Limestone, red sandy ..	at least 1

Little Whickhope Burn (between Saughy and Whickhope Linn faults). Scattered exposures of strata dipping gently to the south in and near Little Whickhope Burn, between 150 and 550 yd downstream from the confluence with White Sike, and also in the lower part of Saughy Sike [6904 8427], are combined in the following composite section (thicknesses only approximate):

	ft
Shale, grey	6
Sandstone, thick-bedded fine-grained	2
Sandstone, fine-grained shaly ..	7
Shale, grey; ironstone nodules ..	2
Sandstone, grey fine-grained calcareous	4
Shale, debris only seen	15
Sandstone, thin-bedded fine-grained; some shaly partings ..	7
Shale, grey; a few plant fragments; a 1-in coaly layer	10
Sandstone, fine-grained	2
Shale, grey; some coal debris; poorly exposed	10
Sandstone, fairly thin-bedded fine-grained micaceous	20
Not exposed	6

	ft
Shale, grey; a few plant fragments	8
Not exposed	12
Sandstone, fine-grained; mostly thick-bedded with false-bedding	20

The section ends against a south-south-easterly fault [6906 8474]. Between this fault and the Whickhope Linn Fault, farther north, exposures in the burn and on its steep east bank at Whickhope Linn form the following sequence:

	ft
Sandstone, grey-brown fine-grained argillaceous slightly calcareous; veined by calcite close to Whickhope Linn Fault ..	about 4
Shale, debris only seen ..	about 5
Sandstone, thin and irregularly bedded fine-grained ferruginous	9
Shale, grey; plant fragments; a 4-in shaly coal near the top..	about 12
Sandstone, thin-bedded fine-grained; shaly partings	10
Shale, grey; carbonaceous at top..	10
Sandstone, thin-bedded fine-grained	16
Shale, grey	about 8
Sandstone, thin-bedded rubbly fine-grained..	about 9
Shale, grey micaceous; partly silty in lowest 3 ft; coaly partings near top	15
Sandstone, thin-bedded fine-grained micaceous; plant fragments	3⅓
Coal, shaly in lower part.. ..	¾
Shale, grey; roots; carbonaceous in top 4 in	1⅔
Sandstone, shaly fine-grained micaceous; ferruginous in bottom 2 ft	5
Shale, grey silty micaceous; plant fragments	4
Sandstone, fairly massive fine-grained sparingly micaceous poorly cemented; ferruginous in part	4
Shale, grey micaceous; silty except at base..	about 3½
Coal, shaly; 1-in shale parting 3 in from top; 14 in	—
Fireclay-mudstone, grey ..	about ¾
Mudstone, grey silty	2
Sandstone, thin-bedded shaly fine-grained micaceous	3
Shale, grey silty slightly micaceous; sandstone partings..	2
Not exposed	12
Sandstone, fine-grained slightly calcareous; a few shell fragments	4
Not exposed; some shale and coal debris	about 12
Shale, grey; poorly exposed ..	12
Sandstone, fine-grained; much plant debris	about 2
Shale, grey; poorly exposed	about 5
WHICKHOPE LINN LIMESTONE	
Limestone, grey argillaceous; shale partings; *Conularia sp.*, *Caninia sp.*, *Lithostrotion sp.*, *Fenestella sp.*, *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Echinoconchus punctatus*, *Productus garwoodi*, *Semiplanus sp. nov.*, and *Spirifer* cf. *trigonalis* (loc. 85b)	7
Shale, grey; a few plant fragments and rare brachiopod and bryozoan fragments; a few calcareous sandstones up to 2 in thick ..	25
Sandstone, grey brown-weathering false-bedded fine-grained calcareous sparingly micaceous; rather flaggy towards top; few roots in top few inches; shell debris; calcite-coated E.–W. and N.–S. joints ..	6
Not exposed	about 2½
Shale, grey calcareous; a few crinoid columnals and brachiopods including *Semiplanus sp.*; E.S.E. joints with calcite ..	about 3
Sandstone, thin-bedded calcareous; crinoid columnals; E.S.E. joints with calcite are cut by others striking S.S.E.	2

In the original survey Miller recorded the 14-in coal in the middle of this sequence as being 13 in thick and worked at crop. Together with the 9-in seam about 18 ft higher, it probably represents the Clock's Cleugh coals (p. 139). One of the two gaps in the sequence, between 19 and 47 ft above the Whickhope Linn Limestone, can be filled by reference to the following section exposed in the burn above Whickhope Linn [6904 8482]:

	ft
Shale, carbonaceous	½
Coal, shaly	¼
Shale, grey; coaly films; plants and roots	½
Mudstone, pale grey; plant debris	6
Shale, grey carbonaceous; coaly streaks; roots	2
Not exposed	about 2½

	ft
Sandstone, thin-bedded fine-grained; shale partings	about 2

In Cross Sike, which joins Little Whickhope Burn on the east [6906 8474], the upper part of the Whickhope Linn sequence is repeated, and still higher beds were formerly seen, though they were obscured at the time of the resurvey. In the following section measured by Miller, the lowest item corresponds with the 12-ft bed of shale lying 30 ft below the top of the Whickhope Linn sequence:

	ft
Sandstone, thick partly massive	30 to 40
Probable limestone	—
Shale; some calcareous bands and 3 to 4 ft sandstone	75
Sandstone, not massive	about 7
Not exposed	35
Shale	10

The thick sandstone at the top of this Cross Sike section makes a continuous line of crags from Saughy Sike [6906 8419] to the Whickhope Linn Fault [6950 8488]. It is thought to be the correlative of the Seven Linns Sandstone (p. 139). The underlying 'probable limestone' was recorded by Miller as being impure and 3 to 4 ft thick in Saughy Sike.

Strata above the Seven Linns Sandstone crop out in the forest south-east of Cross Sike, where three fine-grained, false-bedded sandstones are seen in low craggy escarpments. All are about 20 ft thick and their bases are estimated to be 110, 180 and 280 ft respectively above the base of the Seven Linns Sandstone. The top of the lowest sandstone is ochreous and calcareous where seen in a tributary of Saughy Sike [6933 8427]. Miller recorded a 15-in coal close beneath the middle sandstone [6915 8412].

Little Whickhope Burn (between Whickhope Linn and Elf Kirk faults). Strata below the Shilburnhaugh Coal have been measured as follows in Little Whickhope Burn between 700 and 1400 yd S. of Whickhope Lodge, and in the steep eastern side of the valley:

		ft
Sandstone (forming Raven's Nest Crag), false-bedded fine-grained siliceous [6911 8504]		20 to 30
Shale, grey; coaly streaks		½
Not exposed		3
Sandstone, fine-grained		1¼
Coal		½
Shale, grey; roots and fragmentary plants; some ironstone nodules and coaly partings		13
GREY'S CRAGS COAL		
Coal, shaly	14 in	
Fireclay-mudstone, grey	16 in	
Coal	4 in	
Fireclay-mudstone, grey	14 in	
Coal	7 in	4½
Shale, grey; rooty at top		2¾
Sandstone, fairly thin-bedded fine-grained; a 4-ft shale near the base		14
Shale, grey; silty above, carbonaceous in middle, rooty below		6
Sandstone, fine-grained; thin-bedded and shaly at top; thick-bedded in lower part except at base where it is flaggy; a poorly exposed median shale parting		about 17
Mudstone, silty; fragmentary shells and bryozoa; a 1-in ferruginous bed near base; top 2 ft not exposed		12½
Sandstone, massive fine-grained slightly calcareous and ferruginous		4
Not exposed; some carbonaceous shale debris at base		18
Sandstone, fine-grained; flaggy at top and bottom		about 12
Not exposed; some shale and carbonaceous shale debris		about 32
Sandstone, flaggy false-bedded fine-grained		about 6
Not exposed		about 30
Shale,grey		4
Not exposed		3
Shale, grey silty micaceous; more sandy towards top with a few sandstone partings; some ironstone nodules; about 3 ft above base is a calcareous bed with crinoid columnals, '*Camarotoechia*' *sp.*, *Linoproductus sp.*, *Productus* cf. *garwoodi*, *Straparollus sp.*, *Aviculopecten eskdalensis*, *A. sp.* and ostracods (loc. 85c)		9
Sandstone, grey flaggy fine-grained; a few fragmentary plants		3
Shale, silty micaceous; a few sandstone partings; fragmentary plants		8
Not exposed; old adits to the LITTLE WHICKHOPE COAL (thickness not known)		2
Shale, silty; poorly exposed		4
Coal, shaly, 6 in on carbonaceous shale 6 in		1

	ft
Shale, grey silty micaceous; a few roots	3
Sandstone, massive false-bedded fine-grained ferruginous	12
Shale, grey; a 4-in calcareous siltstone containing shell fragments [688 853]	3

Lower strata are seen in Hen Sike close above the confluence with Little Whickhope Burn [6864 8564] half a mile S. of Whickhope Lodge; they consist mainly of shales, carbonaceous in part. Higher strata crop out in the forest east of Little Whickhope Burn, but only a few crags of sandstone are visible. In the same fault-block, but a quarter of a mile east of the district (Sheet 13), is an exposure of the Plashetts Coal. The seam is 5½ ft thick and is important in providing the key to the structure of this area (p. 108).

Jock's Pike. Several sandstones are mapped on the northern slopes of Jock's Pike [670 846] but little is known of the strata intercalated with them. Around the headwaters of Hen Sike and the unnamed sike running north to Bull Crag, a coal has been worked by adits and shallow shafts [6734 8536 and 6762 8513]: it is here called the Hen Sike Coal. Miller (on his field map) gives the following section in Hen Sike [6762 8513]:

	ft
Sandstone, calcareous	10
Coal [HEN SIKE]	1½
Coal, shaly, and underclay ..	1
Sandstone	—

The sandstone which forms the roof of the coal is visible [6760 8525], 100 yd to the north-west, and is fine-grained with some brachiopod fragments.

Lower down Hen Sike, near the Hope House road crossing [6813 8542] are exposures of fine-grained sandstones, with shale partings and with a pyrite nodule 6 in across.

Back Burn (south of Stower Hill). The base of the Upper Border Group is drawn conjecturally below scattered exposures of sandstone [6522 8466 to 6540 8504] in Short Cleugh—a south bank tributary of Back Burn. In Back Burn itself, somewhat younger measures are exposed near the Forestry Commission bridge [6556 8505] and for 300 yd downstream as follows (loc. 82b):

	ft
Sandstone, flaggy fine-grained ferruginous and micaceous; thin silty micaceous shale partings	10
Limestone, irregularly thin-bedded argillaceous; shale partings; *Fenestella sp.*, *Dyscritella nana*, *Buxtonia sp. nov.*, *Linoproductus sp.*, *Leiopteria sp.* and *Sanguinolites sp.*	3
Strata, including an 8-in coal near the top, and some flaggy sandstone; poorly exposed	about 10
Sandstone, fine-grained siliceous	3
Shale; thin sandstone partings; poorly exposed	10
Sandstone, grey fine-grained; thin shale partings; shell debris; one fossil filled with sphalerite	1½
Shale, grey silty calcareous; shell debris towards top, plant debris below	10½
Sandstone, thin-bedded fine- to medium-grained, slightly micaceous; thin shale partings; some bedding planes covered with worm tubes (for petrography see p. 218) ..	9½
Shale, grey micaceous; a few ostracods at the top and plant fragments below	2¾
Coal .. .. .. ½ in	—
Mudstone, grey micaceous silty; some roots	3½
Sandstone, hard grey flaggy fine-grained	2

West of the bridge, a narrow north-westerly vein of nail-head calcite crosses the burn.

North of this section a sandstone, at least 35 ft thick, makes a prominent feature on the hillside [6536 8526 to 6584 8510]. Its outcrop across the burn is almost entirely obscured by drift, but its base is seen again in an unnamed southern tributary [6609 8501] where 15 ft of brown, thin-bedded, fine-grained sandstone form a waterfall. The 3 ft of strata immediately below are not seen, but they may include a coal, for beneath them are 6 ft of grey shale with plants and roots. Higher up this sike [6653 8469] are small exposures of grey shale with a 1½-in coal.

Low Cranecleugh. In Cranecleugh Burn, south-east and south of Low Cranecleugh, the following section (loc. 86) is exposed, partly along the strike:

	ft
Shale, grey micaceous; a ¼-in coal near top	3
Sandstone, brown fine-grained thick-bedded; erosion at base; coal fragments (for petrography see p. 218)	9

	ft
Shale, grey micaceous silty; an 18-in bed of argillaceous sandstone	3¼
LOW CRANECLEUGH COAL	1¼
Not exposed	about 3
Siltstone, dark grey hard calcareous	1¾
Chert, black	¾
Siltstone, dark grey hard calcareous	1¾
Sandstone, grey (weathering brown) fine-grained calcareous; some plant debris in top part; a 3-in grey silty shale parting near the middle	2
Shale, grey micaceous; silty in part; plant fragments	2⅓
Shale, carbonaceous	¼
Shale, grey; silty at top, calcareous below, hard partings; '*Camarotoechia*' *sp.*, *Leiopteria divisa*, *Modiolus sp.* and *Sanguinolites sp.*	2¾
Limestone, dark grey argillaceous thick-bedded; many thin alternations of greater or lesser siltiness [6612 8549]	1½
Not exposed	40
Limestone, weathering brown argillaceous; *Dyscritella nana*, *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Productus garwoodi*, *Punctospirifer scabricosta*, *Euphemites sp.* and *Leiopteria divisa* [6614 8545]	1¼
Not exposed	5
Shale, grey calcareous; a bedding plane crowded with *Naiadites crassus*	½
Limestone, argillaceous; '*Camarotoechia*' *sp.*, *Lingula* aff. *squamiformis*, *Bellerophon sp.*, *Naiadites crassus*, *Polidevcia attenuata*, *Sanguinolites* cf. *clavatus* and *Schizodus sp.*	1

The 9-in chert in this section is the only chert noted in the Upper Border Group in the north-eastern part of the district. At its northern end the section is faulted, the northernmost exposure being a brecciated, calcite-veined face of limestone, trending at 160°. The stratigraphical position of these strata and those farther north-west in Little Cranecleugh Burn is uncertain, though on structural grounds and on the presence of *Dyscritella nana* they should be low down in the group.

The following section is seen in the right bank of the burn [6614 8526] below Hunger Bog. It is mapped as lying on the south side of the Elf Kirk Fault, the course of which is conjectural:

	ft
Shale, grey	½
Limestone, grey (weathering brown) argillaceous silty; plant and shell fragments	1⅓
Coal 2 in	—
Siltstone, hard grey; plants and roots; soft at top	1¼
Coal 1 in	—
Fireclay-mudstone, grey	¾
Shale, grey; coal streaks; much plant debris	5
Sandstone, brown thin-bedded fine-grained	3
Shale, grey; silty beds	6
Sandstone, flaggy argillaceous; slightly calcareous beds	3

Little Cranecleugh Burn. In Little Cranecleugh Burn and its tributaries exposures are small and discontinuous. They include thin limestones and coals, but no fossils have been collected nor can a connected sequence be made out. In the burn [6531 8627], 1150 yd W.N.W. of Low Cranecleugh, Clough recorded calcareous flags during the primary survey. North of Stower Hill [6486 8618] a fine-grained sandstone about 20 ft thick and calcareous at the top has been mapped for a short distance. Higher upstream [6472 8621] north-west of Stower Hill, 2 ft of slightly calcareous, thin-bedded, fine-grained sandstone with fragmentary fossils rest on 2 ft of grey shale overlying 3 ft of fine-grained sandstone. In the cleugh side to the north, shale and coal debris mark the position of a seam about 20 ft above the exposure in the burn.

In a tributary burn [6498 8653] nearly half a mile N. of Stower Hill, massive sandstone overlies a sandy limestone, which contains crinoid ossicles and pebbles of coal.

The stone pillar [6383 8698] on Scald Pike stands on a crag of massive sandstone about 20 ft thick. Flaggy sandstone is exposed in Craggy Burn [6534 8709] north of Kateshaw Hill.

Whickhope Burn. Two long sections have been measured in Whickhope Burn. The western and lowest measures, around Bull Crag, are separated from the eastern, higher measures by an alluvial reach of the burn which is half a mile long and estimated to conceal about 750 ft of the succession. Both sections are given in detail in Appendix I, p. 316.

Downstream from the higher section, the Jock's Pool Limestone is mapped, but not exposed. In the burn [6893 8650] and in an adjacent old quarry, a quarter of a mile east of Whickhope Lodge, are 25 ft of flaggy, calcareous and micaceous sandstone with sparse shell, crinoid and bryozoan fragments. Farther east, around the confluence of the Whickhope and Little Whickhope burns, are exposures of sandstone, and still farther downstream are disconnected exposures of sandstone and shales as well as limestones up to 2 ft thick. The highest stratum seen in Whickhope Burn is the sandstone forming Grey's Crags [6922 8675 and downstream] half a mile E.N.E. of Whickhope Lodge. This sandstone is fine-grained, thin-bedded and false-bedded (for petrography see p. 219), and is about 25 ft thick. Immediately below it a

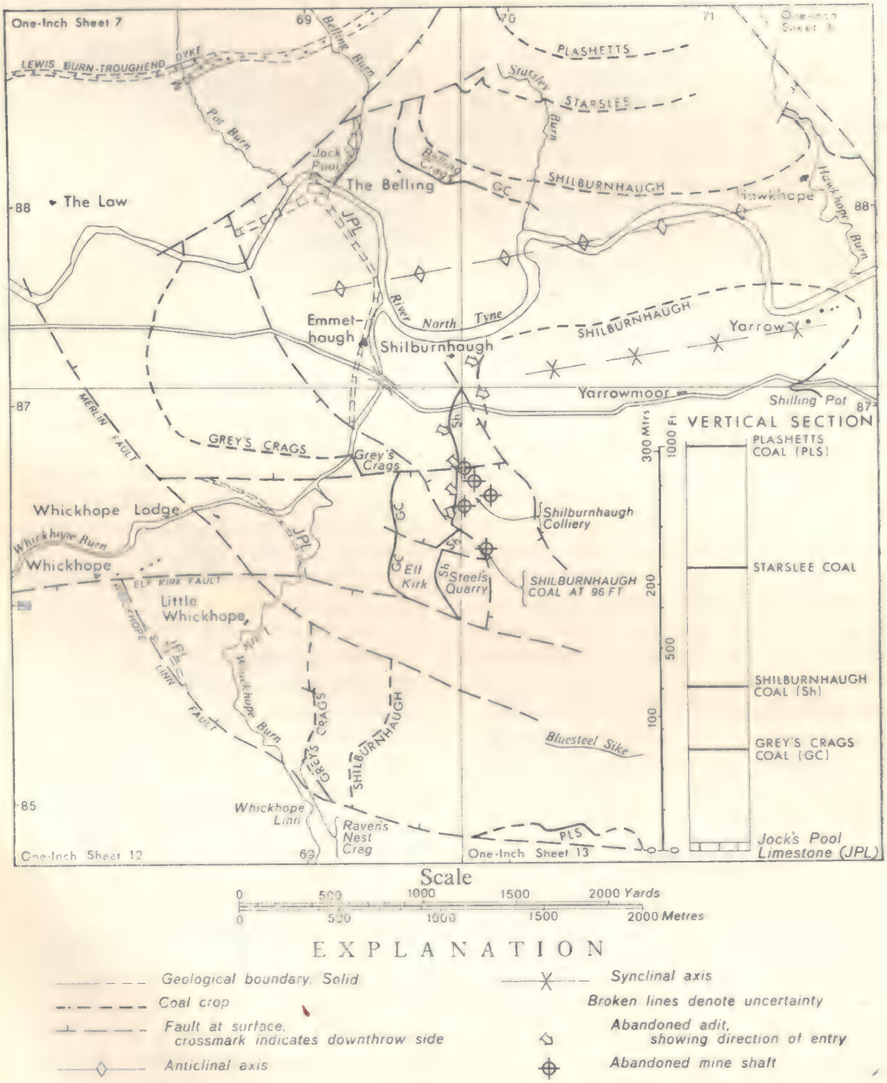


FIG. 27. *Sketch-map showing the geology of the Shilburnhaugh area*

coal has been mined from old adits on the left bank: this coal is here named the Grey's Crags Coal. It is thought that the sandstone of Grey's Crags is the same as that of Belling Crags, 1 mile to the north in the Kielder (Sheet 7) district (Fig. 27).

Area north of Whickhope Burn. In the rising ground north of Whickhope Burn exposures are few and widely separated and consist mainly of sandstone. Some silty shales are seen in the headwaters [around 6642 8700] of Otterstonelee Burn.

Area east of Whickhope Lodge. The Shilburnhaugh Coal crops out at the extreme north-east corner of the district, and for three-quarters of a mile southwards its outcrop lies just within the margin of the district (Fig. 27). During the late 19th and early 20th centuries the seam was worked in this ground from three adits [6971 8686; 6975 8669 and 6974 8656] each driven south-eastward into the hillside and on a slight rise for drainage. The coal dips north-eastward at about 1 in 6. An airshaft 140 yd east of the district margin [6989 8628] proved the following section (Miller, in MS and 1887, p. 31):

		ft
Clay		15
Girdles		4
Sandstone		46
Shale		27
SHILBURNHAUGH COAL		
Coal ..	14 in	
Shale band	18 in	
Coal ..	14 in ..	nearly 4

The bottom leaf of the seam thins northwards. Considerable reserves of coal still remain in the adjacent Bellingham district (Sheet 13).

The sandstone above the Shilburnhaugh Coal forms the summit of the hill [6975 8611] at Steel's Quarry. The stone is massive, false-bedded, fine-grained and siliceous, and was formerly worked in two small quarries [6975 8614 and 6978 8605]. Sandstones and intercalated shaly strata lying below the Shilburnhaugh Coal are poorly exposed along the hillside. D.H.L.

LEWIS BURN CATCHMENT

Lewis Burn. Upper Border Group strata cropping out north of the Harrett's Linn Fault, north of Burnt Tom, are described by Fowler (1966). Exposures falling within the limits of this district are restricted to the east bank of Short Cleugh [6274 8715], where the dip is at 70° to E.S.E. and where a 12-in coal with sandstone roof and floor appears to have been tried in a small adit. Higher strata a few yards farther to the south-east include a 4-in decalcified sandy limestone with fragmentary brachiopods, and a massive fine-grained sandstone at least 50 ft thick.

Lishaw Burn. In the headwaters of Lishaw Burn and on the surrounding moors are scattered exposures of fine-grained, false-bedded sandstones. A crag [5888 8354], half a mile W.N.W. of Stot Crags, is formed by 12 ft of sandstone with irregularly contorted bedding. At the mouth of Foxhole Sike [5919 8377] and in Lishaw Burn to the south, flaggy and massive sandstones form a north–south anticline. From 100 to 200 yd farther downstream, Lishaw Burn flows through a gorge [5927 8388] cut in massive, false-bedded, fine-grained sandstone with some shale partings; the strata are here disposed in a gentle syncline. In the headwaters of Lishaw Burn [5863 8338], 1100 yd W. of Stot Crags, a 6-in coal with shale roof and floor was seen during the primary survey.

Yett Burn. (loc. 88) Around the headwaters of Yett Burn, the lowest strata assigned to the Upper Border Group are seen in a gorge [6002 8287 to 6015 8290], just over 1 mile S.W. of spot height 1374 on Gill Pike. The section is

	ft
Sandstone, massive false-bedded fine-grained; lowest 4 ft coarser grained and ferruginous; coal scars at base	15
Shale, silty; carbonaceous at base	$\frac{1}{3}$
Fireclay-mudstone, grey	$\frac{1}{2}$
Sandstone, flaggy fine-grained micaceous; roots at the top ..	2

The sandstone of the top of this section is also exposed in Stony Sike [6024 8277], 200 yd S.E. of the gorge, and on the moor to the west [near 5967 8283 and near 5920 8270] where it is 30 ft thick and where the bedding is irregularly contorted. A higher sandstone, about 15 ft thick, makes a parallel craggy feature across the moor, but is cut off by the Rough Grain Fault before reaching Yett Burn.

Near the head of Slaty Grain, between Burnt Tom and Grey Mare's Crags, the following section is exposed [6058 8225]:

	ft
Shale, grey	½
Coal, shaly	⅓
Fireclay-mudstone, grey	1
Shale, blue-grey; fragmentary plants	2
Shale, brown; thin shaly sandstone beds; plant fragments	7
Shale, grey	4

Downstream, Slaty Grain runs in a small gorge [605 825] cut through 70 ft of false-bedded, fine-grained sandstone which is partly massive and partly thin-bedded. Farther downstream, to the confluence with Yett Burn, there are only interspersed exposures of flaggy sandstones, representing about 200 ft of strata.

At and immediately north of the confluence [6035 8297] the basal part of the sandstone which forms Grey Mare's Crags is exposed

	ft
Sandstone, brown fine-grained; thin silty shale partings	10
Shale, silty	3
Sandstone, flaggy ripple-marked fine-grained; silty shale partings ..	6
Shale, grey; silty in top foot ..	3½
Sandstone, fine-grained calcareous; shell fragments	¼
Shale, grey; carbonaceous in top 2 in	2½
Sandstone, flaggy; silty shale partings	8

The overlying 70 ft or so of strata are represented only by small exposures of sandstone. Still higher strata crop out about 100 yd north of the confluence where the section [6036 8305] is

	ft
Sandstone, flaggy fine-grained calcareous; thin silty shale partings; plant fragments and shells; lowest 3 in very calcareous, with *Punctospirifer scabricosta*	7
Shale, grey calcareous silty; *Naiadites crassus*	2
Not exposed	2
Mudstone, grey shaly calcareous; ostracods	1½
Limestone, carbonaceous thin-bedded; ostracods	¼
Shale, grey; carbonaceous in top inch	3

The carbonaceous limestone looks and fractures like coal, but in thin section (E 32795) is described by Mr. R. K. Harrison as containing "abundant organic debris in subparallel alignment, with a calcite cement. There are sparse grains of clastic quartz, streaks of carbon and of pale brown feebly anisotropic to isotropic collophane, which give a rather poor X-ray diffraction pattern (NEX 348) of apatite. Veinlets of secondary calcite traverse the specimen, and some of the organic remains have strings of fine sulphide."

Above this section is an unexposed interval representing about 70 ft of strata, extending up to the lowest of the exposures around the mouth of Stot Sike. These exposures show considerable irregularity in dip and strike, but a succession can be made out as follows:

	ft
Sandstone, strongly false-bedded, fine- to medium-grained flaggy and ripple-marked; silty shale partings in lowest 3 ft [6041 8322]	16½
Not exposed	4
Sandstone, false-bedded thin-bedded	3
Not exposed	2
Mudstone, grey; bands of silty shales and thin sandstones; poorly exposed	3
Mudstone, grey (weathering brown) silty slightly calcareous; plant fragments, *Aviculopecten eskdalensis* and *Edmondia sp.*	1
Calcite-mudstone, grey finely laminated	½
Shale, grey	¼
Shale, coaly	¼
Coal	⅓
Shale, carbonaceous	¼
Shale, grey locally silty; plant debris at top	8
Not exposed; some outcrops of flaggy sandstone	about 24
Sandstone, flaggy fine-grained; lower half calcareous; '*Camarotoechia*' *sp.*, productid fragments, *Punctospirifer scabricosta* and *Myalina* cf. *pernoides*	4
Not exposed	about 3
Mudstone, grey silty calcareous; shell debris	1½
Shale, grey; a few silty beds ..	8
Mudstone, silty calcareous; shell debris	1½

	ft
Sandstone, flaggy ripple-marked micaceous; carbonaceous films	4
Not exposed	about 6
Sandstone, flaggy [6038 8310]	2

Downstream from this section, Yett Burn is crossed by the Gill Pike North Fault, on the northern, upthrow side of which are strata correlated with those cropping out in Slaty Grain. They are as follows [6050 8334]:

	ft
Sandstone, greenish brown fine-grained; strongly jointed; thin-bedded above, false-bedded below	about 37
Not exposed; some shale debris	about 18
Shale, grey calcareous; more calcareous fossiliferous beds and dark argillaceous limestones up to 6 in thick; *Lingula* aff. *squamiformis* and ostracods collected 2 ft from top; other fossils include turreted gastropod indet., *Myalina* cf. *pernoides*, *Sanguinolites* cf. *clavatus* and *Schizodus sp.*	8
Shale, grey silty	1
Sandstone, fine-grained siliceous; ferruginous specks and calcareous nodules; carbonized plant fragments at base	4
Shale, grey; septarian nodules; *Myalina sp.*, *Modiolus sp.* and ostracods	1
Shale, grey	5
Sandstone, greenish (weathering brown) fine-grained calcareous; carbonaceous plant fragments; *Aviculoptecten* cf. *subconoideus*, *Myalina sp.* and orthocone nautiloid	about ¾
Shale, grey-brown	1
Shale, carbonaceous	about ⅓
Shale, grey; a few silty bands; ostracods; plant fragments at top	about 15

The 37-ft sandstone at the top of this section can be followed westwards for a quarter of a mile across the moor in a line of crags. Another sandstone, estimated to be 48 ft higher in the succession, crops out to the north in a parallel line of crags; it is a massive, false-bedded fine-grained rock over 30 ft thick.

Farther down Yett Burn, scattered exposures include 3 ft of grey and brown, silty, micaceous shale [6077 8358] overlain by 1 ft of fine-grained, decalcified sandstone containing *Fenestella sp.*, '*Camarotoechia*' *sp.*, *Composita* cf. *ambigua*, *Punctospirifer scabricosta*, *Aviculopecten sp.* and *Myalina* cf. *pernoides*.

West of Gill Pike, a sandstone crosses the burn and can be traced westwards for almost half a mile: it is thought to be the sandstone of Grey Mare's Crags (Fig. 26). About 300 ft higher in the succession is the prominent sandstone which forms the summit of Gill Pike. This sandstone crosses Yett Burn immediately south of the Beckhead–Binky Linn Fault; it is not exposed in the burn, but both to east and west it forms prominent crags which locally exhibit irregularly contorted bedding.

Gill Pike. The interfluvial area between Yett Burn and Back Burn is almost drift-free, apart from peat; and numerous exposures of false-bedded, fine-grained, siliceous sandstones can be seen. In places the bedding is irregularly contorted, notably 300 yd N. of Grey Mare's Crags [6127 8284], and at Sighty Crags [605 818] (not to be confused with Sighty Crag). Other exposures consist of shales and silty shales, but they are few and small. D.H.L

REFERENCES

ANDERSON, W. 1953. In *Summ. Prog. geol. Surv. Gt Br.* for 1952, 31–2.

BARRETT, B. M. and RICHEY, J. E. 1945. Economic geology of the Canonbie Coalfield. *Wartime Pamph. geol. Surv. Gt Br.*, No. 42.

CLOUGH, C. T. 1889. The geology of Plashetts and Kielder. *Mem. geol. Surv. Gt Br.*

CUMMINGS, R. H. 1961. The foraminiferal zones of the Carboniferous sequence of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 107–28.

FOWLER, A. 1936. The geology of the country around Rothbury, Amble and Ashington. *Mem. geol. Surv. Gt Br.*

—— 1966. The stratigraphy of the North Tyne basin around Kielder and Falstone, Northumberland. *Bull. geol. Surv. Gt Br.*, No. 24, 57–104.

GARWOOD, E. J. 1931. The Tuedian Beds of northern Cumberland and Roxburghshire, east of Liddel Water. *Quart. Jl geol. Soc. Lond.*, **87**, 97–159.

LUMSDEN, G. I., TULLOCH, W., HOWELLS, M. F. and DAVIES, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

—— and WILSON, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

MILLER, H. 1887. The geology of the country around Otterburn and Elsdon. *Mem. geol. Surv. Gt Br.*

SIMPSON, J. B. 1953. In *Summ. Prog. geol. Surv. Gt Br.*, for 1951, 38–43.

SMITH, S. 1912. *Report of the committee appointed to report upon the Carboniferous Limestone formation of the north of England, with special reference to its coal resources.* Newcastle upon Tyne.

—— 1911. The faunal succession of the Upper Bernician. *Trans. nat. Hist. Soc. Northumb.*, **3**, 591–645.

TATE, G. 1867. Miscellanea geologica for 1866. *Proc. Berwicksh. Nat. Club*, **5**, 283–9.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

WESTOLL, T. S., ROBSON, D. A. and GREEN, R. 1955. Guide to the geology of the district around Alnwick. *Proc. Yorks. geol. Soc.*, **30**, 61–100.

Chapter VI

LIDDESDALE GROUP

General Account

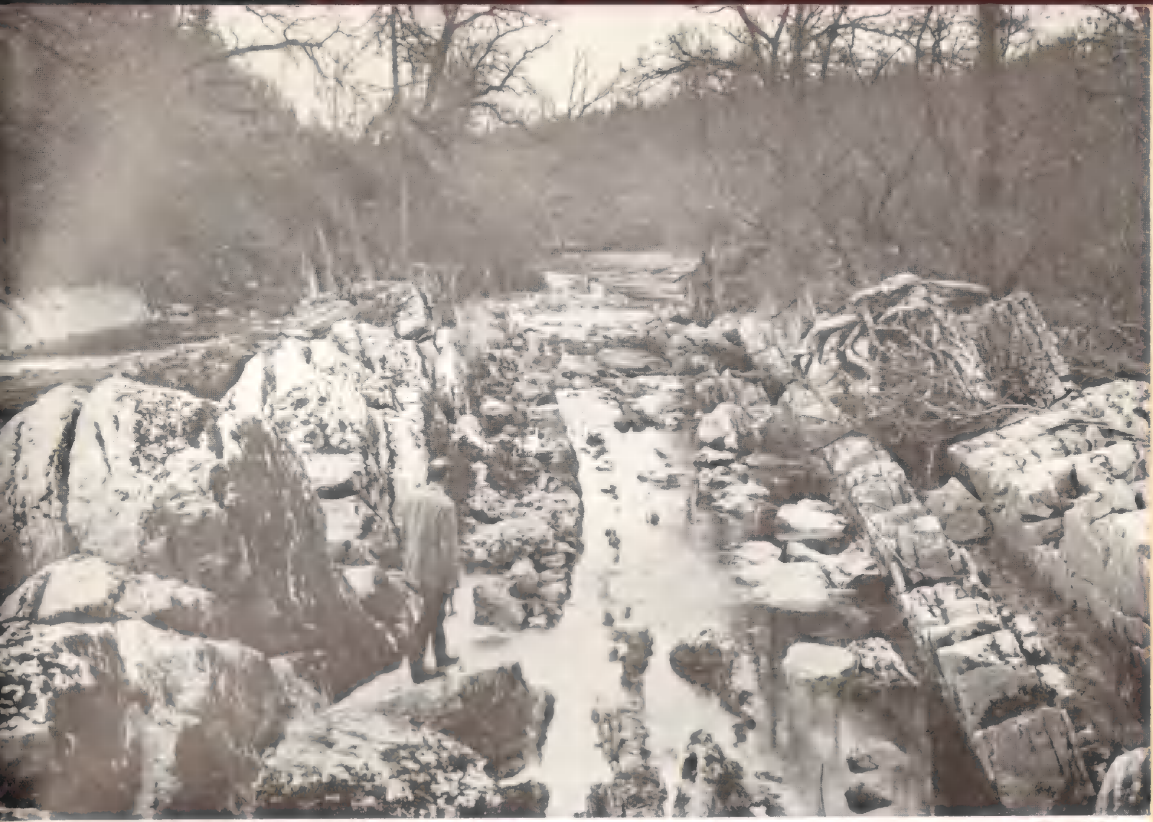
The Liddesdale Group is here defined as extending upwards from the base of the Dinwoodie Beds and the equivalent Goat Island Limestone and Naworth Bryozoa Band to the base of the Catsbit or Great Limestone. It thus approximates to the combined Lower and Middle Limestone groups of the earlier classification in Cumberland and Northumberland (p. 10).

Rocks of the group crop out only in comparatively small areas in the Liddel, Lyne and Lower Irthing–Tipalt catchment areas. Complete successions, shown graphically in Fig. 28, are known only at two localities, both immediately adjacent to the district described here. One is the Archerbeck Bore (Lumsden and Wilson 1961), north of the Scottish Border, but within the western margin of the sheet; the other is to the south-east in the ground around Greenhead (partly covered by the Brampton (18) Sheet), where exposures in the Tipalt Burn are supplemented by the Cairny Croft Bore (Trotter and Hollingworth 1932, pp. 199–200). The group is 1746 ft thick at Archerbeck as compared with 2280 ft at Greenhead, the east-south-easterly thickening being almost entirely taken up within the upper part of the sequence.

The group is believed to embrace the whole of coral-brachiopod D_1 and D_2 zones and probably the whole of the goniatite P Zone. The boundary between D_1 and D_2 zones probably lies at the base of the Callant Limestone of Archerbeck which is equivalent to a horizon at about the middle of the Low Tipalt Limestone of Greenhead. In the following pages this horizon is also used to subdivide the group into Lower and Upper divisions, though no attempt at this distinction has been made on the one-inch map.

The group consists of rhythmically deposited sediments, the lithology of which shows a marked change from deltaic shales and massive sandstones below to a preponderance of thick marine limestones above. In the west, this change coincides with the base of the Callant Limestone, but around Greenhead it seems to have taken place rather earlier, at about the Denton Mill horizon. It can be calculated from the log of the Archerbeck Borehole that the proportion of limestone in the upper part of the group is more than double that in the lower, whilst the proportion of shale is almost halved.

The sequence from the Penton Limestone up to a sandstone 80 ft above the Harelawhill Limestone is magnificently exposed in the Liddel Water at Penton Linns (Appendix I, p. 289) and has been the subject of much previous research. Peach and Horne (1903) included these beds in the 'Lower Limestone Group', correctly deducing their approximate position in the Lower Carboniferous succession and suggesting a general correlation with the sequence below the



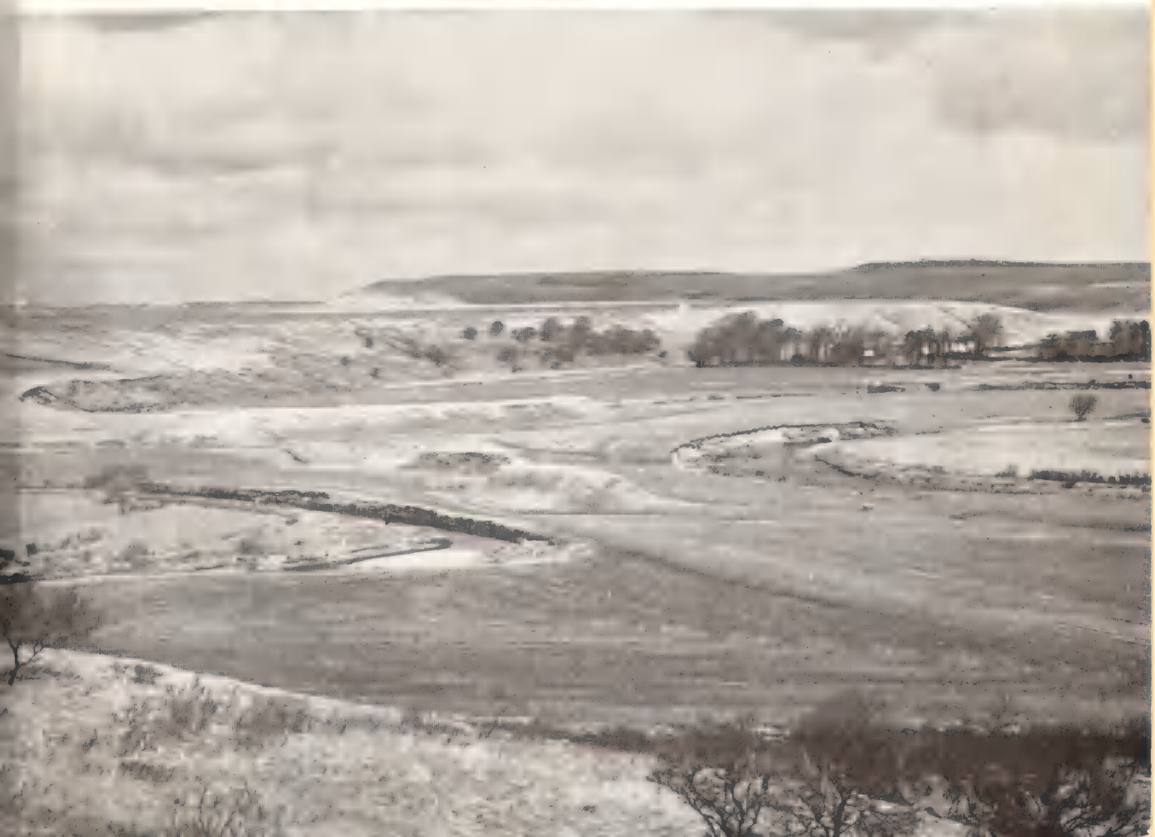
(L 481)

A. Harelawhill Limestone (right) and Gastropod Limestone (left); Penton Linns, Liddel Water

PLATE VII

B. River Irthing (right) at its confluence with Butter Burn

(L 440)



Dryburn (Great) Limestone of Northumberland. Barrett and Richey (1945, fig. 3) correctly assigned the limestones of Penton Linns to a position below the Catsbit Limestone, but made no attempt at correlation other than to suggest a comparison with the Scottish Carboniferous Limestone of the Midland Valley. Both pairs of authors confused the Kilnholme Coals with the Penton Coals, which were placed in a 'coal-bearing group' by Peach and Horne and in a 'Limestone Coal Group' by Barratt and Richey. During the resurvey of the Bewcastle (12) Sheet, a detailed correlation was proposed (Anderson 1953, p. 31) between the Penton Linns limestones and the Middle Limestone Group of Northern England. During the accompanying revision north of the border, Lumsden (1953, p. 38), recognizing the lack of detailed resemblance to the Scottish Midland Valley succession, proposed as an interim measure the name 'Penton Limestone Group'.

The Archerbeck Borehole, drilled in 1954, provided the first full sequence below the Catsbit Limestone and confirmed its similarity to the North of England succession. The bore also revealed the presence of the Buccleuch Limestone (Four Fathom Limestone of the Alston Block) which is not seen at outcrop, and proved several limestones below the Penton (Greengate Well) horizon. In consequence it became possible to relate to the Lower Liddesdale Group previously undescribed measures in the Liddel Water at Hudd's Hole and The Pot.

Despite difference in thickness, firm correlation can be made on lithological grounds alone between Liddesdale and Greenhead. From Greenhead the correlation can be carried to the Alston Block, although in the case of the Bankhouses Limestone confusion has arisen from a discrepancy between text, diagrams and appendix in the Brampton Memoir (Trotter and Hollingworth 1932). Reference to field maps shows that the (Greenhead) Bankhouses of the diagram (op cit., figs. 6 and 7) is correctly named, but that the naming of the Bankhouses and Low Tipalt limestones in the Cairny Croft Borehole log (op. cit. p. 199) is incorrect. In fact, the (Greenhead) Bankhouses occurs at 153¼ ft in this bore, and the Low Tipalt at 213 ft. The discrepancy led Johnson (1959) to assume that there are three Bankhouses limestones, which he named Lower, Middle and Upper; of these the 'Middle' is the (Greenhead) Bankhouses, while the Lower is the Low Tipalt.

It is difficult to correlate the Greenhead sequence with that farther to the east in North Tynedale, largely because the full succession on the Bellingham (13) Sheet has yet to be determined. Smith (1911) first suggested the equivalence of the Redesdale and Naworth limestones, a correlation later supported by Trotter and Hollingworth (1932, pp. 37–8), mainly on lithological grounds. There is some resemblance between the respective sequences and close lithological similarity between the Redesdale Ironstone Shale and the Naworth Bryozoa Band; so-called 'phasal' faunas with similar species contents occur at both horizons. On the other hand, D_1 faunas appear in the Plashett's Dun and Piper's Cross limestones 1000 and 600 ft respectively below the Redesdale (Robinson *in* Westoll, Robson and Green 1955, p. 81). As there is no evidence of D_1 species in the Upper Border Group of the Irthing (see p. 195), there are good palaeontological grounds for equating the Plashett's Dun Limestone with the Naworth Limestone, and the Piper's Cross and Redesdale limestones with horizons much higher than the Naworth.

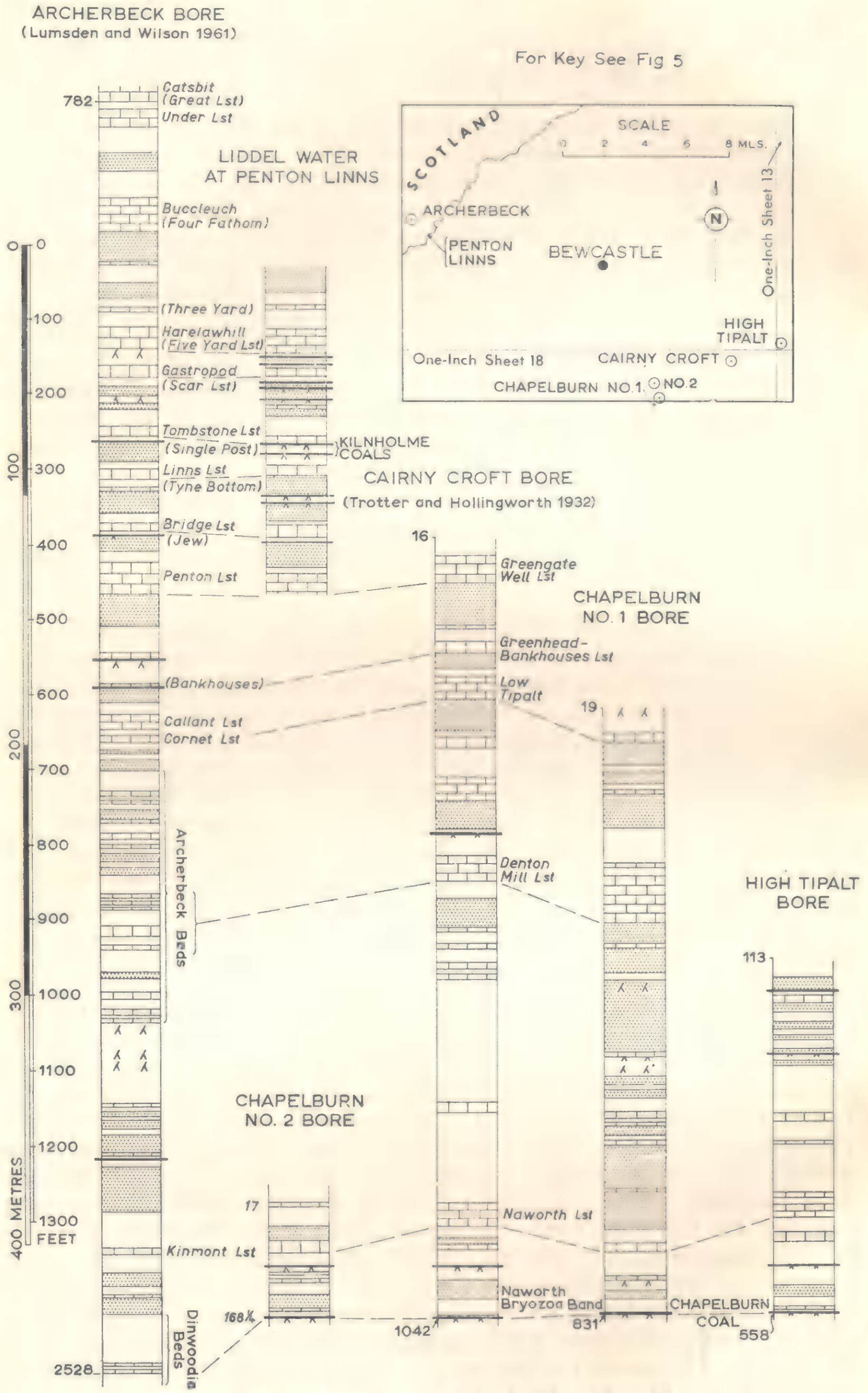


FIG. 28. *Comparative vertical sections of the Liddesdale Group*

Lower Liddesdale Group

LIDDEL CATCHMENT

Lower Liddesdale Group strata are exposed in a stretch of river between the Watleyhirst Fault and an east–west fault crossing the river south-west of Pudding Crook. The lowest beds crop out discontinuously along both banks near The Pot [4487 7948], where they consist of current-bedded sandstone, locally with rootlets. A note on the old-series field-map mentions a 2-foot coal crossing the the river near Francis Ford, and an old bell-pit nearby [4479 7946] suggests that it was worked. The seam is not now visible, however. A short distance above it a 4-foot limestone is exposed in the side of the valley (locs. 91d, e). It is overlain by a thick sandstone which has been quarried south of the railway line [4494 7933] where it is at least 26 ft thick including a 9-ft calcareous, fossiliferous band. The coal, limestone and overlying sandstone are correlated with the measures between 2215¼ and 2189½ ft in the Archerbeck Borehole.

Sandstones still higher in the sequence crop out in the river as far east as the mouth of Nookfoot Sike and are in turn overlain by the following beds exposed in the sike [4594 7956], 50 yd S. of the railway embankment:

	ft
Limestone, hard blue; crinoidal	½
Shale, blue-grey calcareous; fossiliferous (loc. 92d)	½
Limestone, impure blue	3 to 4
Limestone, hard blue; crinoidal ..	6
Shale, blue-grey nodular calcareous; fossiliferous (loc. 92b) ..	8
Sandstone, rubbly	—

Calcareous shales and thin fossiliferous limestones (loc. 92e) crop out intermittently upstream, and similar beds are seen along the strike in a tributary of Nookfoot Sike (loc. 94).

Higher measures are seen in a small stream which enters the Liddel at Huddshole Ford, where the section is:

	ft
Limestone, blue-grey shaly ..	—
Not exposed	3
Shale, calcareous	1
Limestone, hard grey; bivalves indet.	2¾
Shale, calcareous, limestone partings	5
Limestone, hard; crinoidal ..	1¾
Shale, calcareous; fossiliferous ..	2

Farther upstream and about 40 yd west of Blowlowing Farm the highest horizon exposed consists of 4 ft of shaly fossiliferous limestone (loc. 95b).

A well-jointed limestone with a brown-weathering top crops out [4432 7855] on the Scottish bank of the Liddel immediately below the suspension footbridge:

	ft
Shale, grey sandy; ironstone nodules; shell fragments ..	4
Limestone, hard grey; shaly partings; packed with *Productus* cf. *hindi* and *P.* cf. *maximus*	8½
Shale, grey sandy; bellerophontids	5
Limestone, hard grey; *P.* cf. *maximus* and *Dibunophyllum bourtonense*	5½
Shale, calcareous; fossiliferous ..	4
Limestone, shaly	—

The lower of the two limestones has been quarried in the left bank at Boat Pool (loc. 91f). This sequence can be correlated with the limestones at the base of the Archerbeck Beds in the Archerbeck Borehole, and also with beds in Nookfoot Sike (loc. 92). In terms of the Greenhead succession, they probably lie about 100 ft below the base of the Denton Mill Limestone.

The following section, at a slightly lower horizon, is exposed in the right bank [4442 7887] south of Bendal Pool (loc. 91b is at the same horizon on left bank):

	ft
Sandstone, greenish-grey shaly ..	—
Shale, green sandy..	1¼
Shale, blue-grey; ironstone nodules and bivalves	2¼
Limestone, impure; crinoidal ..	1
Shale, dark carbonaceous ..	¼
Coal	¼
Fireclay, hard dark	¼
Fireclay, greenish grey	1
Shale, greenish grey silty, ironstone nodules	1
Shale, dark silty; shells	¾
Ironstone, shelly	¼
Siltstone, hard; passing downwards into shaly sandstone ..	—

LYNE CATCHMENT

River Lyne. The Goat Island Limestone, which has been taken as the base of the Liddesdale Group in the central part of the sheet, is exposed at each end of Goat Island [485 715] and on each side of the Goat Island –Lyne Thrust (p. 116). At the eastern end of the island, the limestone, 2½ ft thick, caps a long section of Upper Border Group rocks exposed upstream (pp. 302–3): it is seen under the overhanging left bank of the river where it is overlain by several feet of red shales and marls which abut against the crush belt formed by the thrust. The shales in the immediate roof of the limestone form a band, up to 1 ft thick, packed with crushed specimens of *Lithostrotion junceum*. This is the first appearance of this coral, usually considered diagnostic of the D_1 Subzone. The best exposure of the Goat Island Limestone west of the fault occurs on the left bank of the river [4835 7123], where it is again overlain by shale containing *L. junceum*. The beds strike upstream in the direction of Goat Island, and the following section can be seen to overlie the Goat Island Limestone in the river bed and in the opposite bank [4838 7143]:

	ft
Sandstone, flaggy; shale bands ..	5
Limestone, red impure	2
Sandstone, flaggy; red shale bands	7
Sandstone, purplish medium-grained flaggy	8
Not exposed	6
Sandstone, yellow (submerged) ..	2
Not exposed	4
Sandstone, yellow	3
Shale, purplish sandy and red marl	11
Marl, red; abundant *L. junceum*	1
GOAT ISLAND LIMESTONE	
Limestone, red; crinoids and rare bryozoa	3 to 4
Marls, red	2
Sandstone, thick; dipping at 10° on right bank and increasing to 45° on left bank	—

The beds at the top of this section appear to be unfossiliferous and thus contrast with equivalent upper part of the Dinwoodie Beds in the Archerbeck Bore (Lumsden and Wilson 1961, pp. 11, 58–9).

Hagg Beck. Isolated exposures of the Lower Liddesdale Group occur in the Hagg Beck east of the Lynedale Fault. They include a thin-bedded, pale buff limestone more than 5 ft thick, which dips westward at 65° and contains a varied fauna including such forms as *Carcinophyllum vaughani* and *Pugilis pugilis* (loc. 97a). A thin red limestone containing small gastropods crops out 300 yd to the south, and mudstones and shales dip southwards in the small tributary just north of Hallsford [475 730]. The following section occurs still farther south [4741 7284]:

	ft
Limestone, bright red	1¼
Mudstone, pale grey sandy ..	8
Sandstone, fine white	15

Here the dip is due south at 20°, and between this exposure and the Lynedale Fault, seen in the stream [4738 7265], the sequence consists mainly of sandstone.

LOWER IRTHING AND TIPALT CATCHMENTS

Tipalt Burn. The whole of the Lower Liddesdale Group succession, extending between the Naworth Bryozoa Band and the middle of the Low Tipalt Limestone (Fig. 28), was proved in the Cairny Croft Borehole (Trotter and Hollingworth 1932, pp. 34, 199–200) just beyond the southern margin of the district. In this bore the Bryozoa Band occurs at 1041 ft, the Naworth Limestone (Kinmont of Archerbeck Bore) at 922½ ft, and the Denton Mill and Low Tipalt limestones at 457½ ft and 213 ft respectively. Trotter and Hollingworth thought that a limestone met at a depth of 213 ft was the Bankhouses, but this limestone is now identified as the bed occurring at a depth of 153¼ ft.

The Naworth Bryozoa Band is not exposed within the Bewcastle district, and the crop shown is conjectural. It was encountered in the Thirlwall No. 1 Bore [6589 6837] at a depth of about 80 ft. It is separated from the Naworth Limestone by sandstones which are exposed in Swallowholes Sike [6632 6863]. The Naworth Limestone does not crop out, but the next limestone, about 150 ft higher in the sequence (at 768 ft in the Cairny Croft Bore) can be seen [6625 6817] in the Toddle Burn where it is at least 8 ft thick, containing *Lithostrotion sp.* (not collected), and is overlain by 12 ft or more of blue-grey shales with ironstone nodules. Higher measures, mainly sandstones and shales, are seen in the burn east of Gorcock, and the Denton Mill Limestone is incompletely exposed [6617 6763] a little to the south of the margin of the district. Except for a very poor exposure in Cat Cleugh [6724 6800] the Denton Mill Limestone is obscured by drift elsewhere on the sheet, but it is mapped as cropping out across the Tipalt Burn in the immediate vicinity of High Tipalt Farm, about 50 yd beyond the eastern margin of the district.

The measures below the Low Tipalt Limestone can be seen as follows in the Tipalt Burn, where they dip southwards at 14° to 18°:

LOW TIPALT LIMESTONE (basal beds)	ft
Limestone, shaly and detrital [6810 6793]	3
Not exposed	15
Sandstone, soft yellow micaceous	10
Not exposed	4
Limestone, massive grey; large productids	10
Limestone, sandy yellow-weathering	2
Sandstone	1
Shale, sandy; sandstone bands ..	6
Not exposed	6
Limestone, detrital yellow-weathering	2
Not exposed – calcareous shale debris	25
Shale, calcareous; fossiliferous ..	10
Mudstone, calcareous; limestone bands; colonies of *Lithostrotion sp.*	8
Limestone	10
Not exposed	4
Sandstone [6871 6828]; for petrography see p. 219	4

UPPER LIDDESDALE GROUP

LIDDEL CATCHMENT

Liddel Water. A particularly good section of the Upper Liddesdale Group is exposed in the Liddel Water west of Penton Bridge (Figs. 28, 29; loc. 99) and is easily accessible from the Scottish bank. About 90 yd west of the bridge, the Penton Limestone forms the core of a sharp anticlinal fold (Pl. I), and in the steeply dipping western limb, extending westwards for 200 yd along the right bank of the river, overlying measures up to a sandstone 80 ft above the top of the Harelawhill Limestone can be seen. They include the Bridge, Linns, Tombstone, Gastropod, Harelawhill and other, unnamed limestones, in addition to a sparsely shelly sandstone which is represented by limestone in the Archerbeck Bore (at 1315 ft) and at Hog Wash farther upstream. Other beds worthy of note are the Rhynchonellid Sandstone, immediately underlying the Linns Limestone, and three coals, between 2½ in and 8 in thick, which occur beneath the Tombstone Limestone immediately west of the mouth of Loup Sike. One of these seams thickens upstream near Kilnholm and has been worked from adits in the left bank.

Details of the section, which closely resembles the sequence proved in the Archerbeck Bore, are given in Appendix I, p. 289.

An extensive fauna has been collected from the limestones and overlying shales (Lumsden and others 1967, p. 151). The lower part of the Penton Limestone (not seen in the Liddel but present in the Archerbeck Bore) contains the highest local development of prominent *Girvanella* haloes. The highest occurrence of *Lithostrotion pauciradiale* is in the shales overlying the Tombstone Limestone, and that of *L. junceum* in the lower part of the Harelawhill Limestone. *Saccamminopsis fusulinaformis* is recorded from the limestone above the Harelawhill. The entire section falls within Cummings' (1961) foraminiferal zone 7.

The Penton Limestone is correlated (Fig. 28) with the lithologically similar Greengate Well Limestone exposed in the Tipalt Burn, just beyond the southern margin of the district. Both are dark grey calcarenites with a profusion of clastic organic fragments (p. 220). The resemblance extends to the

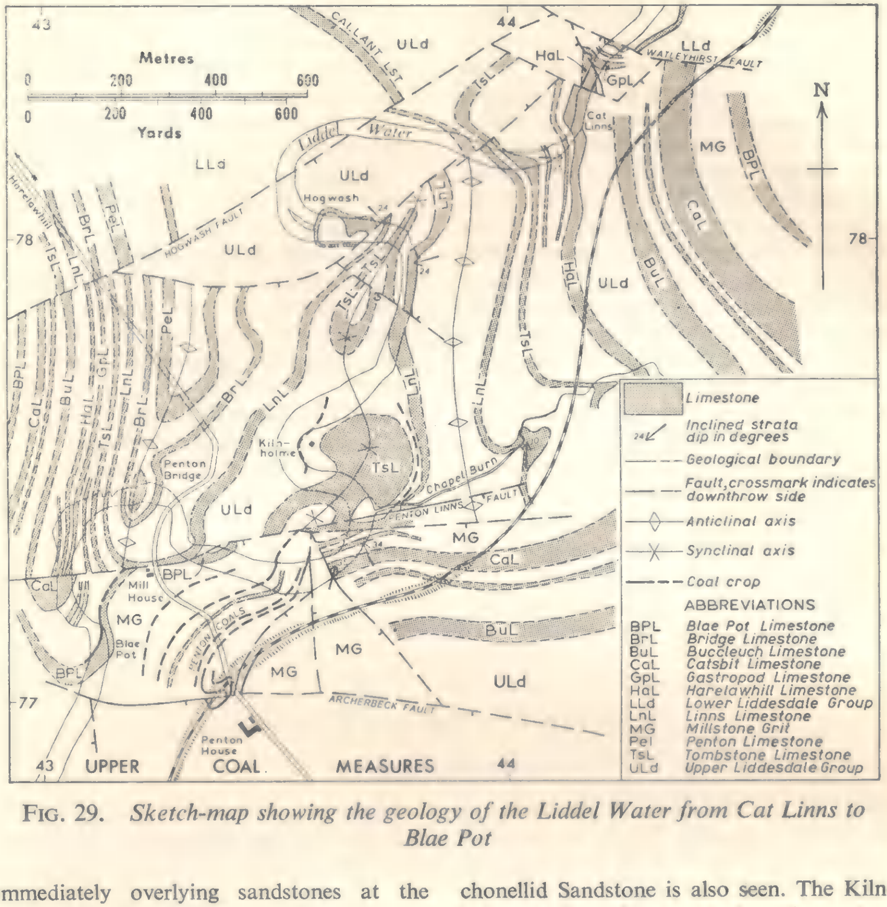


FIG. 29. *Sketch-map showing the geology of the Liddel Water from Cat Linns to Blae Pot*

immediately overlying sandstones at the two localities.

Penton Bridge is founded on the massive sandstone which overlies the Bridge Limestone, the measures here forming part of the eastern limb of the Penton Anticline. The Linns Limestone recrosses the river 120 yd upstream from the bridge and a little to the west of the Penton Linns Fault. Still farther upstream and north of the locality where the Penton Linns Fault again crosses the river just off the mouth of Chapel Burn, several of the limestones and associated beds can again be seen. The Tombstone Limestone crops out in the river, forming a gentle syncline a few yards north of the mouth of Chapel Burn, and the underlying beds down to the Linns Limestone and the subjacent Rhynchonellid Sandstone are exposed in the lowest hundred yards of the stream. Here the fireclays between the thin coals of Kilnholme contain calcareous nodules, and a shelly horizon confusingly similar to the Rhynchonellid Sandstone is also seen. The Kilnholme coals are best exposed on the western limb of a syncline in the left bank of the river, immediately east and north of Kilnholme itself. One of the coals attains a local thickness of 14 in and has been worked. The coals are associated with bands of nodular, calcareous fireclay, similar to those from the mouth of the Chapel Burn; one such band, 50 yd S. of Kilnholme, consists almost entirely of limestone, the top of which closely, but superficially, resembles the typical 'knobbly tops' of some of the Lower Border Group algal limestones.

North of Kilnholme the beds are somewhat undulatory, but after once again crossing the main synclinal axis, a long strike-section of the Linns Limestone is exposed along the north–south stretch of the river west of Peter's Crook. The river swings westward 250 yd N.W. of this farm, and once again crosses the syncline formed by the Tombstone Limestone with the Linns

Limestone emerging from beneath on the western limb. At this locality the river is crossed by a fault, downthrowing to the east, and between it and Hogwash Island gently flexed beds lying about 25 ft below the Linns Limestone can be seen. A 2½-ft limestone [4360 7802] forming a shallow waterfall at the eastern end of the island occurs at a depth of 1315 ft in the Archerbeck Bore, but in the Penton Linns section it appears to be represented by a shelly sandstone.

The sequence between the Linns and Harelawhill limestones is again seen in the Liddel Water north of Peter's Crook at Dormont Pool (loc. 101); and at Cat Linns (loc. 100) there are old quarries in Harelawhill Limestone on both banks of the river. This limestone strikes upstream, and its crop is terminated northwards by the Hogwash Fault. From there to the Watleyhirst Fault, a further 100 yd upstream, beds lying between the Gastropod and Linns limestones form a disturbed section dipping south-westwards at about 35°.

Chapel Burn. The tract of country between the Hilltop and Back Burn faults is probably all underlain by Liddesdale Group. The following section may be seen 185 yd E.S.E. of Kingfield House, where the dip is 70° to north-west:

		ft
Shale, blue-grey; ironstone nodules at top, crinoidal at base [4584 7779]		15
Limestone, massive creamy blue; shaly at top		4
Limestone, shaly blue-grey; *Lithostrotion junceum*	loc. 103a	3
Shale, calcareous; crinoidal		2½
Not exposed		9
Shale, calcareous; productids		1
Limestone, fine creamy-blue ..		3
Not exposed		6
Limestone, fine creamy-blue massive; crinoids and irony spots		3½
Limestone, fine blue massive hard; partly hematitic and yellow-weathering		3¼
Mudstone, grey; red blotches ..		3¾
Shale, black		¼
Mudstone, soft grey		1
Not exposed; thickness unknown		—
Sandstone, red medium-grained massive; flaggy bands [4586 7778]		33
Shale, red and yellow; rotten ..		4
Sandstone, red and yellow; massive		6
Shale, red rotten		6
Shale, blue calcareous; thin limestone ribs		6
Shale, blue		6
Not exposed; thickness unknown		—
Sandstone, red and yellow, fine-grained; clayey partings [4588 7777]		15
Sandstone, purple and yellow bleached clayey		6
Sandstone, brown medium-grained massive; red at top		15
Sandstone, grey flaggy		12
Not exposed; some shale debris ..		—
Limestone, grey shaly		½
Not exposed		2
Mudstone, grey sandy; hard ribs ..		3
Coal and carbonaceous shale ..		¼
Shale, grey rooty		1¼
Fireclay, grey		1
Mudstone, grey blocky		3
Not exposed		4
Limestone, blue massive; calcite-veined, crystalline		3¾
Not exposed		1¼
Ganister, fine grey rooty		2

The lithology of the strata forming the upper part of the section suggests that they might be the correlatives of the Archerbeck Beds (Lumsden and Wilson 1961, p. 10). Limestone containing *L. junceum* is also exposed [4525 7816], 700 yd farther downstream (loc. 103b).

Carwinley Burn. Reddened measures, believed to be of Upper Liddesdale Group age, crop out between two faults in the Carwinley Burn [4213 7342], 500 yd S.W. of Hillback Bridge. They consist of about 120 ft of alternating sandstones and shales with rare thin red limestones. Their position in the sequence is uncertain. To the west of the two faults, however, the Penton Limestone is exposed at a sharp bend in the stream [4209 7347] dipping a little to the west of north at 80°. Downstream the section is:

	ft
Limestone, purplish-grey massive; corals and shells encrusted with *Girvanella sp.*, algal nodules (loc. 104)	50
Sandstone, purple flaggy ..	40
Shale, sandy; becoming calcareous towards the base; abundant *Syringopora sp.*, ...	10

	ft
Limestone, impure red	1
Limestone, reddish-grey massive	6
Shale	4
Sandstone, flaggy	1

LOWER IRTHING AND TIPALT CATCHMENTS

Tipalt Burn. No beds of Upper Liddesdale age are known to crop out anywhere in the central part of the district, but in the south-east they are exposed in Tipalt Burn. There is an excellent section of the Low Tipalt Limestone in a small, disused quarry on the right bank of the stream [6799 6795] 350 yd W. of Low Tipalt Farm. Johnson (1959, p. 116) described it as 'Lower Bankhouses Limestone' and as having the affinities of a reef-knoll of Cracoe type. The succession in this quarry (and the adjacent stream-bed) is:

	ft
Limestone, grey shelly detrital	up to 10
Limestone, massive reef-bedded detrital; abundant colonies of *Lithostrotion*, *Syringopora*, etc., some of which are inverse	10
Limestone, impure shaly detrital; rare poorly-developed *Girvanella* haloes	2–3

The overlying sequence can be made out in the opposite (left) bank of the stream:

	ft
GREENHEAD BANKHOUSES LIMESTONE	
Limestone	6
Shale, calcareous	4
Limestone	2½
Shale, calcareous; limestone nodules	2
Sandstone, rooty	1
Sandstone, massive	12
Sandstone, flaggy; for petrography see p. 220	4
Rhythmically alternating bands of flaggy sandstone and sandy shale	10
Shale, sandy	6
LOW TIPALT LIMESTONE	—

These measures are intruded by a thin dolerite dyke on the left bank [6808 6792], 20 yd E. of the mouth of a small streamlet.

Although there is evidence for the doming of the Low Tipalt Limestone, it is here interpreted as a tectonic feature—possibly associated with small-scale faulting—rather than as a quaquaversally-dipping, true reef-knoll. The limestone maintains both its thickness and detrital character along the strike to the west where it is again exposed 800 yd E. by N. of Greengate Well Farm. Furthermore, the external appearance of the cores of its correlative limestones (Callant and Cornet) in the Archerbeck Bore suggest that its reef-like characteristics extend as far west as Canonbie. J.B.W.D.

REFERENCES

ANDERSON, W. 1953. In *Summ. Prog. geol. Surv. Gt Br.*, for 1952, 31–2.

BARRETT, B. M. and RICHEY, J. E. 1945. Economic geology of the Canonbie Coalfield. *Wartime Pamph. geol. Surv. Gt Br.*, No. 42.

CUMMINGS, R. H. 1961. The foraminiferal zones of the Carboniferous sequence of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 107–28.

JOHNSON, G. A. L. 1959. The Carboniferous stratigraphy of the Roman Wall district in western Northumberland. *Proc. Yorks. geol. Soc.*, **35**, 83–130.

LUMSDEN, G. I. 1953. In *Summ. Prog. geol. Surv. Gt Br.*, for 1952, 38.

—— TULLOCH, W., HOWELLS, M. F. and DAVIES, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

—— and WILSON, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

PEACH, B. N. and HORNE, J. 1903. The Canonbie Coalfield: its geological structure and relations to the Carboniferous rocks of the north of England and central Scotland. *Trans. R. Soc. Edinb.*, **40**, 835–77.

SMITH, S. 1911. The faunal succession of the Upper Bernician. *Trans. nat. Hist. Soc. Northumb.*, **3**, 591–645.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

WESTOLL, T. S., ROBSON, D. A. and GREEN, R. 1955. Guide to the geology of the district around Alnwick. *Proc. Yorks. geol. Soc.*, **30**, 61–100.

Chapter VII

LOWER CARBONIFEROUS PALAEONTOLOGY

THE LOWER CARBONIFEROUS ROCKS of the present district are chiefly notable for the remarkable development of calcareous algae which they contain in their lower part. These were first described from the Kershope area by Nicholson (1888), and formed the subject of further studies by Garwood (1913b, 1914, 1931). Garwood's work of 1931, with its appendix on brachiopods by Muir-Wood, remains the only substantial general palaeontological contribution, and the present study has confirmed his principal conclusions.

Lists of the fossils collected during the resurvey are given on pp. 191–9.

LOWER BORDER GROUP

The algae, so characteristic of these beds, and their ecological significance, are discussed at length in a separate section below (see p. 175).

The fauna is in general an impoverished one, but is considerably more varied than is found in apparently equivalent horizons in the Cementstones of Northumberland. As is common in impoverished faunas, although the number of species is small individual species often occur in large numbers.

Mollusca and ostracods are common in the shales. The molluscs usually belong to long ranging forms, but *Modiolus latus*[1] is especially characteristic, as are species of *Myalina*, *Parallelodon*, *Polidevcia*, *Leiopteria* and *Aviculopecten*. Turreted gastropods and bellerophontoids are the common gastropods.

Brachiopods are limited in number of species, though in places they crowd bedding planes. *Antiquatonia teres* (Plate XII, fig. 4.), which is the species most typical of the group, also occurs in the Whitberry Band at the base of the Middle Border Group. *Pustula interrupta* at the base, *Schuchertella ambigua* ranging throughout the group, and *Cleiothyridina glabristria* and *Syringothyris exoleta* near the top are the other main features of the brachiopod fauna. All are species known in Tournaisian and lower Viséan rocks elsewhere.

Corals are recorded only from one horizon at the top of the Lower Border Group, where *Aulopora*, *Michelinia* and *Palaeosmilia* were collected by Garwood (1931). Annelids—*Serpula* and *Spirorbis*—are common in the limestones; they are commonly associated with algae.

Dr. J. E. Robinson reports that the ostracod fauna of the group is essentially of Tournaisian type. He reports that there are two typical ecological associations among the ostracods—a ?brackish water assemblage characterized by *Carbonita* [*Argilloecia*] *sp. Cavellina sp.* and *Knoxiella sp. nov.* 2 and a marine assemblage with *Bairdia*, *Beyrichiopsis*, *Punctomosea* and *Graphiadactylus*. Some ostracod faunas, however, do not agree closely with either of these.

---

[1] The authors of species mentioned are given in the lists of fossils at the end of this chapter.

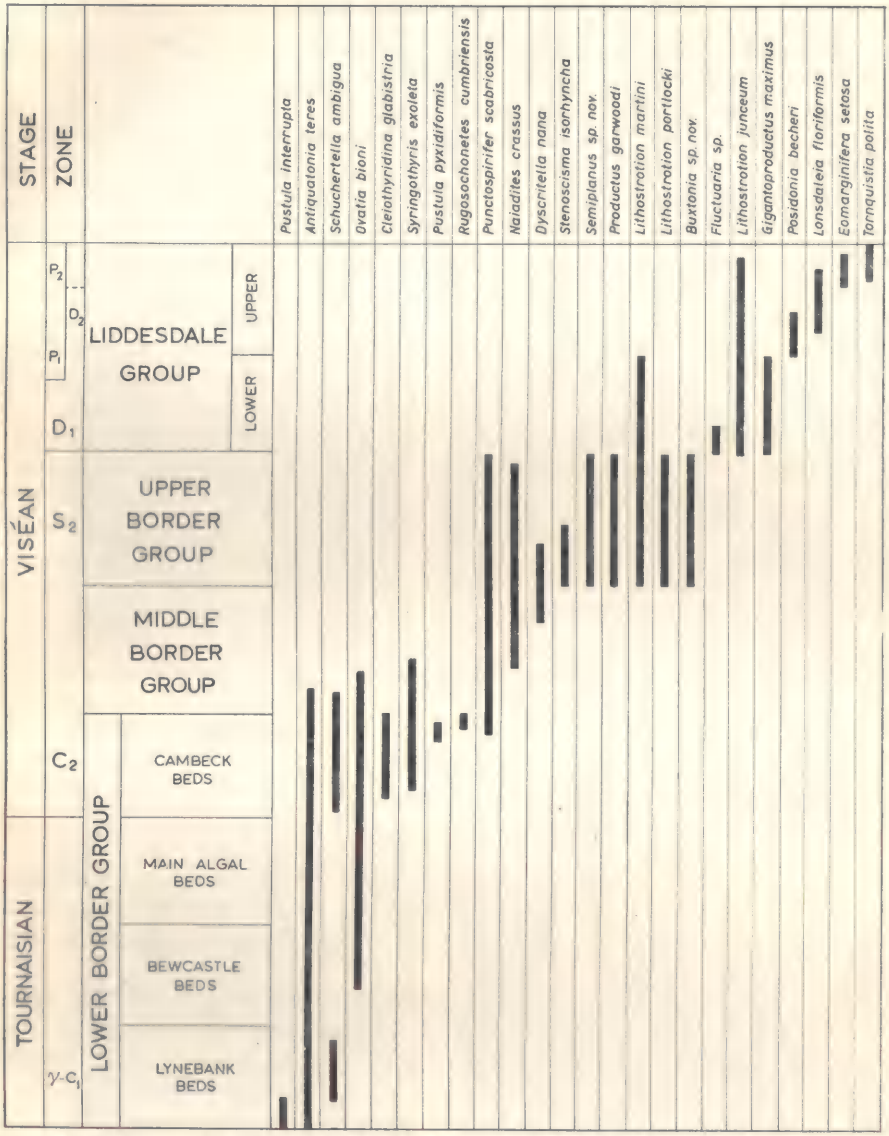


FIG. 30. *Ranges of stratigraphically significant fossils in the Lower Carboniferous*

The zonal position of that part of the Lower Border Group below the Cambeck Beds cannot be conclusively demonstrated. None of the macrofossils is diagnostic of a Tournaisian horizon, but since there are about 2400 ft of beds containing Tournaisian ostracods below the entry (in the Cambeck Beds) of diagnostically lower Viséan species of macrofossils it is reasonable to conclude that such beds are of Tournaisian age. Moreover many of the species are typical of those found in beds placed in the Tournaisian elsewhere. There is no evidence as to how low in the Tournaisian the beds reach, but a horizon lower than γ/C_1 is unlikely.

These conclusions differ from that of George (1958, pp. 241, 295) who suggested that beds older than the Viséan were absent in this area. The diagnostic

Viséan fossils implied by George to be typical of the whole of the Cementstones occur, however, only in the uppermost division—the Cambeck Beds—which are also referred to the Viséan in this account.

The Cambeck Beds at the top of the group were placed by Garwood in the C_2 Zone of the Lower Viséan, and there is no reason to doubt this conclusion. It is based on the presence of *Cleiothyridina glabristria* and *Pustula pyxidiformis*, both known to occur in C_2 elsewhere. Also indicative of this horizon is *Palaeosmilia murchisoni* near the top of the Cambeck Beds. It seems, however, that an ostracod fauna of Tournaisian type persists into these basal Viséan beds.

The following plants from the Lower Border Group of the district are in the Institute's collections: *Alcicornopteris convoluta* Kidston, *Archaeocalamites radiatus* (Brongniart), *Calymatotheca sp.*, cf. *Diplotmema patentissimum* (Ettingshausen) [figured Kidston 1923, pl. 54, fig. 5], *Lepidostrobophyllum lanceolatum* (Lindley and Hutton) Bell, *Lepidostrobus ornatus* Brongniart, cf. *Rhodea tenuis* Gothan, *Rhodea sp.* cf. *machaneki* (Ettingshausen), *Spathulopteris decomposita* (Kidston), *Sphenopteridium pachyrachis* (Goeppert), *Sphenopteris sp.* cf. *S.* (*Telangium*) *bifida* Lindley and Hutton, *Sphenopteris sp.* s.l., *Stigmaria sp.* cf. *S. ficoides* (Sternberg). The determinations are by Dr. W. G. Chaloner.

Lynebank Beds. The fauna of the Lynebank Beds is restricted in the number of species. The limestones and calcareous shales yield a few brachiopods, and the mudstones contain mainly a molluscan fauna of little stratigraphical value. Among the brachiopods, *Antiquatonia teres* seems to be peculiarly characteristic of the 'cementstone' facies and is scarcely known outside it. *Pustula interrupta* and *Schuchertella ambigua* are the only stratigraphically useful brachiopods. The former is known from zones Z_2 to C_2 in other areas (Thomas 1914, p. 275); the latter is very close to the form recorded from the Chatburn Limestone (γ/C_1 and C_2) of the Clitheroe area (Ramsbottom *in* Earp and others 1961, p. 175) as *Schuchertella sp. nov.* The species was formerly referred to *Derbyia*, but its median septum is much less developed than in typical members of that Upper Carboniferous genus. The evidence is inconclusive as to the zonal position of the beds, but in view of what lies above them, γ/C_1 is the probable position.

In addition to algae (see p. 179) the limestones also contain abundant annelids, both *Serpula* and *Spirorbis*.

Dr. J. E. Robinson examined two ostracod faunas from Ellery Sike (locs. 3A and 3B) and finds them to be typically Tournaisian assemblages including some possibly distinctive elements in *Beyrichiopsis* cf. *carinata* and *Lichvinia sp. nov.*

Bewcastle Beds. In the Bewcastle Beds the limestones contain mainly algae and serpulids, and the shales mainly molluscs and ostracods. Brachiopods occur at

---

EXPLANATION OF PLATE VIII

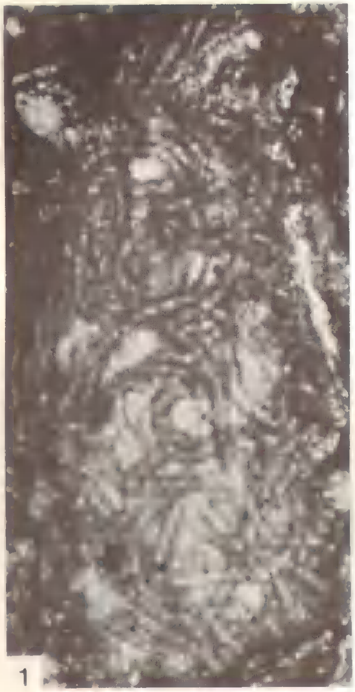
Algae from the Lower Border Group

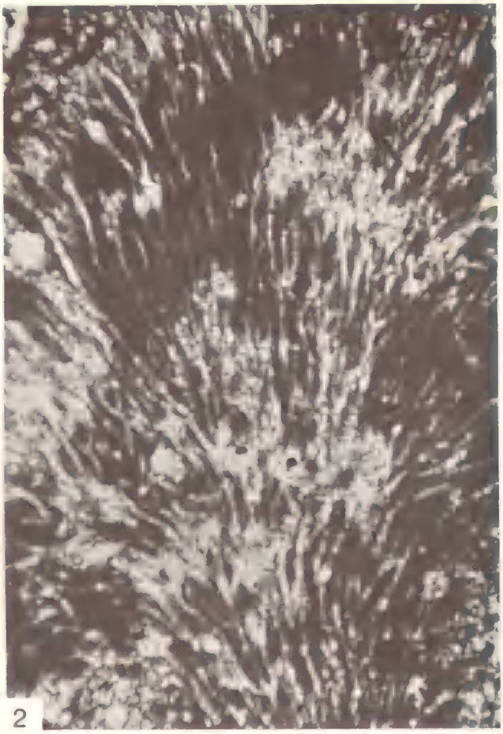
FIG. 1. *Girvanella ducii* Wethered, × 80. Main Algal Beds, Crubinshill Sike (loc. 18). PF 307. See p. 183.

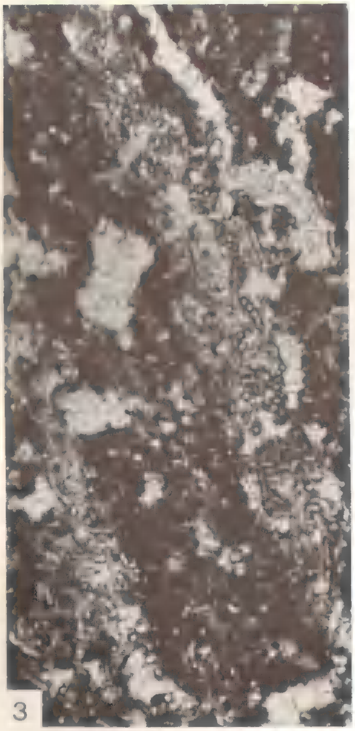
FIG. 2. *Ortonella kershopensis* Garwood, × 80. Horizon and locality as for Fig. 1. PF 343. See p. 183.

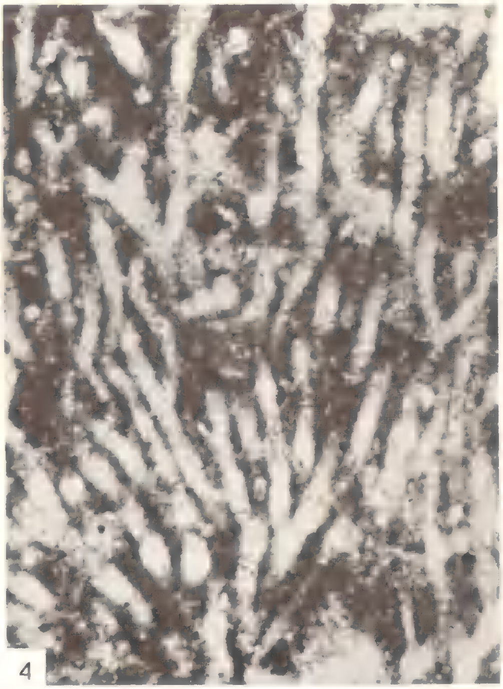
FIG. 3. *Girvanella wetheredii* Chapman, × 80. Lynebank Beds, Ellery Sike (loc. 3), 100 yd N.W. of a point 15 yd N.W. of mouth of Ellery Sike. E 25909. See p. 179.

FIG. 4. *Ortonella furcata* Garwood, × 80. Bewcastle Beds, tributary of White Beck, 330 yd N. 26° W. of Woodhead Farm [5757 7422]. E 25975. See p. 181.


1


2


3


4

ALGAE FROM THE MAIN ALGAL BEDS

a few levels, especially the Bogside Limestone, where *A. teres* and *Composita* aff. *ambigua* are common and the Ashy Cleugh Limestone which contains *Ovatia bioni*. The absence of *Schuchertella ambigua* is noteworthy, particularly as it is also absent in the middle beds of the Chatburn Limestone (Ramsbottom *in* Earp and others 1961, p. 176).

The mollusca include what is probably the lowest British occurrence of the bellerophontoid genus *Euphemites*. Lee (1912, p. 176) mentioned a specimen of the bryozoan *Tabulipora* from Kirk Beck: this is now known to be from the Bewcastle Beds, and the specimen would now be referred to the genus *Stenophragmidium*.

Main Algal Beds. The limestones of the Main Algal Beds contain an algal/annelid association, and many of the larger algal nodules are encrusted around large orthocones in which the internal structure of *Dolorthoceras* is well preserved (Plate XII, fig. 5).

An extensive fauna has been collected only at the level of the *Orbiculoidea* Shale where *Orbiculoidea* and *Lingula* occur together with *Ovatia bioni* and many bivalves, the commonest being species, often large, of *Sanguinolites*. The dentaliid *Plagioglypta* is also common.

Dr. Robinson examined ostracods from the *Orbiculoidea* Shale at Birky Cleugh (loc. 25) and reports them to be of untypical facies, lacking many species found by him in the Main Algal Beds in Liddesdale. These differences are assumed to be ecological.

Cambeck Beds. The Lower *Antiquatonia* Band at the base of the Cambeck Beds contains the richest fauna of the Lower Border Group. From this horizon came the holotypes of *Ovatia bioni* and *Schuchertella ambigua* (Muir-Wood 1931), and other brachiopods found here include *Cleiothyridina glabristria* and *Antiquatonia teres*. At a higher level the *Syringothyris* Limestone contains abundant *S. exoleta* and *Schuchertella ambigua*. Just below the top of the Beds is a limestone characterized by common *Composita sp.*, and at about this level too Garwood (1931, p. 116) recorded from Green's Burn a fauna including '*Michelinia grandis*' and '*Cyathophyllum*'. The first of these is represented in the Garwood Collection by specimens too crushed for specific determination, though possibly the corallites are too small to be *M. grandis*; the second is now determined as *Palaeosmilia murchisoni*, a species not known to occur below the C_2 Zone. The same level in Green's Burn yielded one of the specimens of *Pustula pyxidiformis* figured by Thomas (1914), and this is another fossil common in C_2. The placing of the Cambeck Beds in the C_2 Zone, basal Viséan, is also suggested, as Garwood 1931 stated, by the presence of *Cleiothyridina glabristria*. It may be noted that *Punctospirifer scabricosta* makes its earliest appearance in these beds, and continues upwards in higher formations.

Dr. Robinson examined a collection of ostracods from the Lower *Antiquatonia* Band and reports that it is of typical 'Cementstone' character, agreeing with such faunas from above the Main Algal Beds of Liddesdale. The ostracod fauna is of definite Tournaisian type including such forms as *Punctomosea sp.* and *Knoxiella sp. nov.* 2. It appears that the Tournaisian type of ostracod fauna continues into lowermost Viséan beds. Jones and Kirkby (1886) figured two ostracod species, *Hollinella radiata* and *H. longispina*, as from 'Cam Beck'.

Although the horizon cannot be certain, it is probable that these came from the Cambeck Beds.

MIDDLE BORDER GROUP

The Whitberry Band at the base of the Middle Border Group is characterized by an abundance of *Rugosochonetes cumbriensis*, but the horizon also contains a varied fauna including *Schuchertella ambigua*, *Antiquatonia teres*, *Echinoconchus* cf. *elegans* and many ostracods.

Dr. J. E. Robinson reports that the ostracods from the Whitberry Band in Whitberry Burn include *Bairdiacypris sp. nov.*, *Acanthoscapha sp. nov.*, *Kirkbyella sp. nov.*, *Seminolites sp.*, *Hollinella radiata*, *Monoceratina antiqua*, *Oliganiscus sp. nov.*, and *Glyptopleura sp. nov.*, all of which occur within the lower part of the Upper Border Group in the rivers Irthing and North Tyne. At the same time there are also forms such as *Paraparchites pinguis*, *Cavellina* cf. *longula* and *Glyptopleura* cf. *costata* which are commonly found in the Lower Border Group. He concludes that it is possible to differentiate between an older fauna of Tournaisian aspect and a younger fauna of Viséan type, and that, although there is no dramatic change from one to the other, the ostracod fauna found in the Whitberry Band is 'possibly on the Viséan side of the divide'.

Higher Middle Border Group faunas from the Middle Shield Bore (p. 329) are allied more closely to those found in the Upper Border Group than to those of the Lower Border Group. Upper Border Group species present are cf. *Naiadites crassus*, *Punctospirifer scabricosta*, *Linoproductus sp.* (*corrugatus* group). Forms more typical of the Lower Border Group include *Syringothyris* cf. *exoleta*, *Ovatia* cf. *bioni*, each at one level, and poorly preserved examples of ?*Antiquatonia teres* and ?*Schuchertella ambigua*. *Pteronites angustatus* is common and trepostomatous bryozoa assume importance. The holotype of *Dyscritella nana* is from Trout Beck at a horizon just below the top of the Middle Border Group, and Weir (1931) figured *Retispira undata* from the River Black Lyne at a horizon within the Middle Border Group.

Ostracods from the Middle Shield Bore were examined by Dr. J. E. Robinson who reports that these faunas are similar to those found in the lower part of the Upper Group farther to the north-east (see Table II, p. 330). Old collections of the Institute contain the following Middle Border Group plants, determined by Dr. W. G. Chaloner: *Bothrodendron sp.*, *Lepidostrobophyllum fimbriatum* (Kidston) Allen, and *Lepidostrobus ornatus*. The occurrence of *Pitys primaeva* (Witham) has been referred to on pp. 84 and 97.

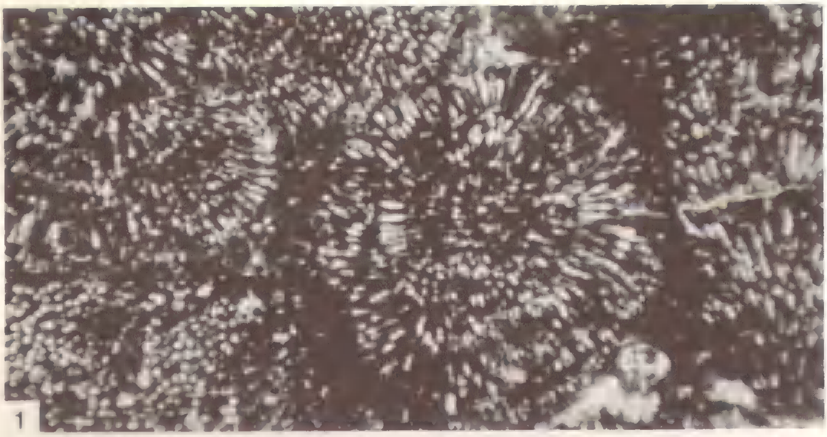
EXPLANATION OF PLATE IX

FIG. 1. *Garwoodia gregaria* (Nicholson), x 15. Cambeck Beds, Cam Beck, 760 yd S. 81 ° W. of Park Gate [5498 7018].
E 25959. See p. 188.

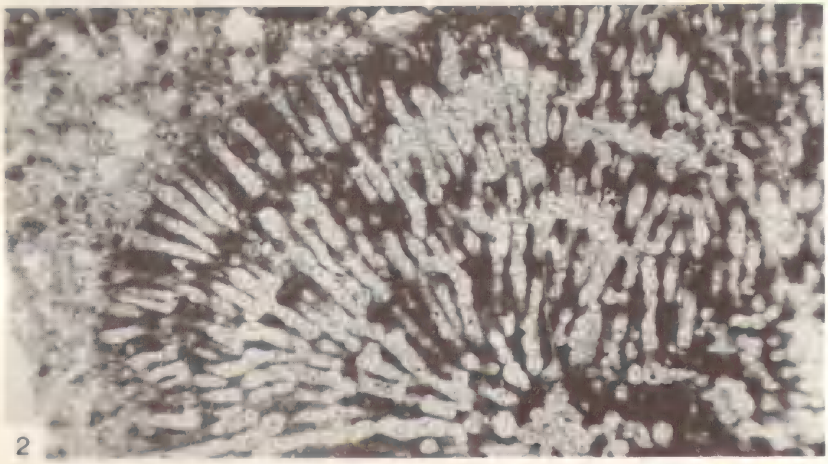
FIG. 2. *Garwoodia gregaria*, × 30. Cambeck Beds, small stream 1310 yd N. 33 ° W. of Spadeadam Farm [579 716]
E 25937. See p. 188.

FIG. 3. *Garwoodia gregaria*, × 100, showing typical branching. Locality and horizon as for Fig. 1.
E 25960. See p. 188.

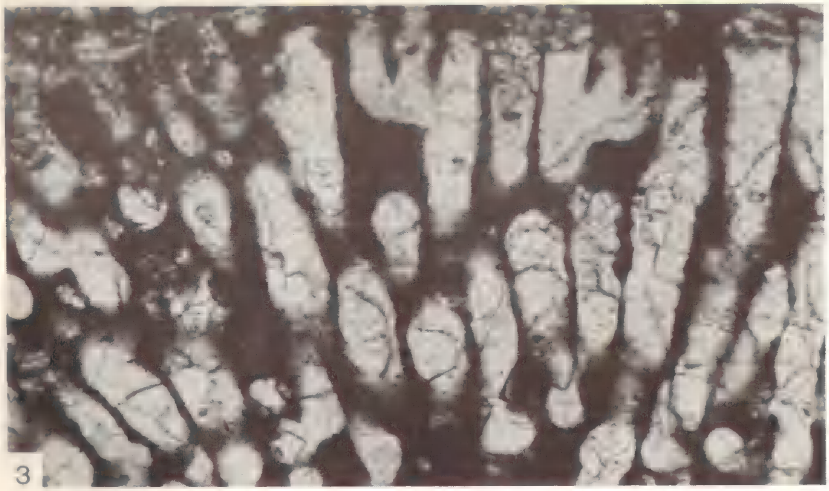
PLATE IX



1

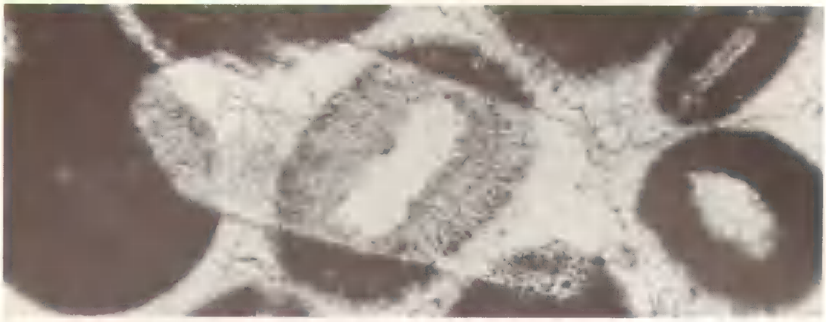


2

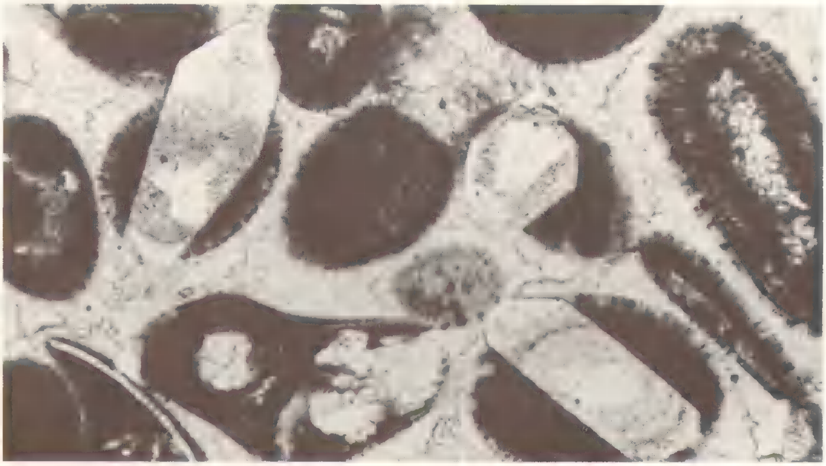


3

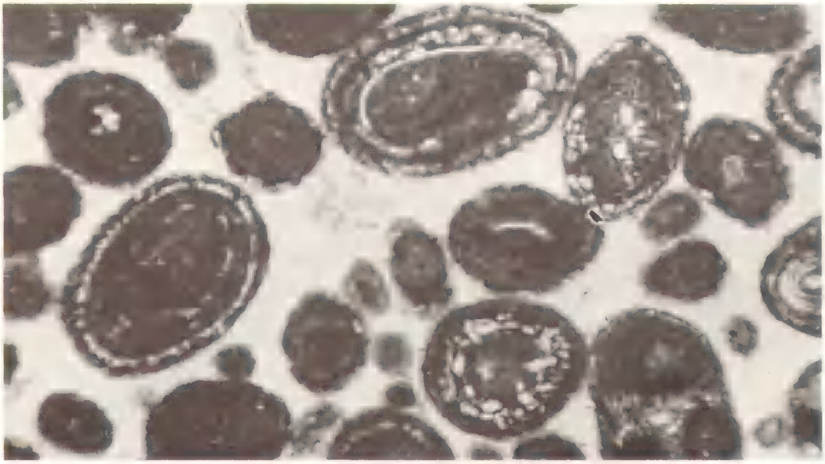
ALGAE FROM THE CAMBECK BEDS



1



2



3

SECONDARY QUARTZ GROWTHS AND ALGAL PELLETS, MAIN ALGAL BEDS

UPPER BORDER GROUP

At the base of the Upper Border Group, in the Clattering Band, a notable faunal change takes place. Colonial corals such as *Lithostrotion martini* and *L. portlocki*, and gigantoproductids determined as *Semiplanus sp. nov.* become common and persist in the limestones throughout the Group. In the Clattering Band in Farloan Sike some of the specimens of *L. portlocki* have corallites showing crenulate margins—a feature also noted in examples from the Burns and Scott beds of the Archerbeck Bore (Lumsden and Wilson 1961). The large *Semiplanus sp. nov.* (Plate XII, fig. 1) is characterized by a very thin shell with scattered spine bases and ill-defined non-dendritic adductor scars—features which distinguish the species from *Gigantoproductus maximus* occurring at higher horizons. There is some evidence that the forms of *Semiplanus* show progressive alteration at successively higher horizons, and the higher forms from the Leahill Limestone are a little more globose and have slightly coarser costae than lower forms, but these features require further study[1].

The Clattering Band (loc. 70f) also contains *Stenoscisma isorhyncha* (Plate XII, figs 2a, 2b), which is restricted to the lower beds of the Upper Border Group, *Stenodiscus sp.*[2], *Echinoconchus punctatus*, *Punctospirifer scabricosta* and *Weberides sp.* With the exception of the trilobite and *S. isorhyncha* the limestones higher in the group have a similar fauna, though in these higher limestones *Echinoconchus* cf. *elegans* and *Productus garwoodi* are also common. Limestones above the Clattering Band also commonly contain *Buxtonia sp. nov.* (Plate XII, fig. 3), which has coarse costae (c. 9 in 10 mm on the trail), but lacks the ventral sinus found in specimens from the Liddesdale Group above, as typified by *B. sp.* figured by Muir-Wood (1928, pl. 12, fig. 20). After being etched in acetic acid specimens of several of these limestones yielded scolecodont remains, but no conodonts.

The shales of the Upper Border Group contain a plentiful molluscan fauna. Notably, they include thin beds crowded with *Naiadites crassus* commonly associated with '*Camarotoechia*' *sp.* and *Hollinella sp.*, thus proving the marine nature of the sediments. However, as inferred by Miller (1887, p. 20), '*Camarotoechia*' is the first of the calcareous brachiopods to enter the broadly equivalent

---

[1] This species was recorded as *Gigantoproductus* aff. *maximus* in Lumsden and others (1967, pp. 116, 149). It appears to be characteristic of the S_2 Zone and is known from the Bryozoa Band (specimen HR 2259) and the S_2 beds above it in Ravenstonedale, where Garwood (1913a, p. 503) recorded the species from Lane Head Quarry as *Productus* cf. *maximus* (specimen in Garwood Collection GSM 64492) in association with *Davidsonina carbonaria* (McCoy). Its occurrence there and its confusion with true *P. maximus*, which is typical of D_1, led Garwood to assign the beds above the Bryozoa Band to D_1, but the association of *D. carbonaria* and *Semiplanus sp. nov.* is sufficient to prove the S_2 age of the beds up to about 30 ft above the Bryozoa Band of Ravenstonedale. At this higher level there is also a change in gross lithology similar to that in other areas of limestone deposition at the S_2/D_1 junction. See also footnote in Fowler (1966, p. 76).

[2] Lee (1912, p. 154) recorded *Stenopora* (now *Stenodiscus*) *redesdalensis* Lee from Clattering Ford. This record was probably based on specimen No. M 1145f which was so named in the registers, but not, apparently, sectioned. Sections now cut from this specimen show that it is significantly different from *S. redesdalensis*.

EXPLANATION OF PLATE X

FIGS. 1, 2. Secondary growth on quartz grains forming the centres of 'ooliths', × 100. Main Algal Beds, Crubinshill Sike (loc. 18). PF 376. See p. 179.

FIG. 3. Algal pellets, mainly concentric growths of *Girvanella*, × 100. Main Algal Beds, M.A.4, Birky Cleugh (loc. 25). PL 308. See pp. 178 and 274.

Scremerston Coal Group as it is traced from its least marine area in the north-east to its most marine area in the south-west of the Northumberland Trough.

Such shales have yielded two of the rare edrioasteroids known from the British Carboniferous, and Sharman and Newton (1892) described *Lepidodiscus milleri* from the River Irthing, 1 mile east of Waterhead, at a horizon now known to be about that of the Millerhill Limestone. Another such edrioasteroid was collected from a similar horizon in the River Irthing at the foot of Linen Sike. In both cases the fossils were adherent on myalinids. The first of these localities also yielded examples of *Tabulipora howsei* cited by Lee (1912, p. 167). He also cited *Dyscritella* aff. *miliaria* from the River Black Lyne opposite Cumcrook, and *Stenophragmidium sparsitabulata* (Lee) from Longcleughside and Hirsthead Sike—all in the Upper Border Group as now defined. Other fossils previously recorded from the district include *Hypergonia quinquecarinata* (de Koninck), cited by Longstaff (1926) from the Clattering Band, and *Bellerophon randerstonensis* figured and cited by Weir (1931) from the River Irthing near Waterhead.

Dr. Robinson examined ostracods from Spadeadam No. 3 (Camp) Bore (p. 334) and from the Clattering Band. Many of the species are also known from the Middle Border Group.

In addition to the animal fossils listed at the end of this chapter, the Institute's collection also contains the following Upper Border Group plants determined by Dr. W. G. Chaloner: *Archaeocalamites radiatus*, *Calathiops sp.*, cf. *Calathiospermum sp.* [cupule], *Diplotmema dissectum* Brongniart, *Lepidostrobophyllum fimbriatum* (Kidston) Allen, *Pinnularia columnaris* (Artis), *Sphenopteridium capillare* Walton, *Sphenopteris* (*Telangium*) *bifida*, and *Sphenopteris sp.* Kidston (1903) figured a specimen of *Pitys primaeva* found loose in the River Irthing between Shank End and Lampert, as well as a number of other plants from the Upper Border Group of the district.

Miospores. Dr. R. Neves and Mr. J. E. Williams of the Department of Geology, University of Sheffield, have reported as follows.

> Miospore assemblages have been examined from eight samples (collected by Dr. W. H. C. Ramsbottom) of coals and shales occurring in the Upper Border Group exposures in the River Irthing. Well preserved spores were found at all of the horizons investigated but the diversity of the assemblages, in terms of numbers of species present, was generally poor. Very few species of restricted stratigraphic range were recorded which to some extent reflects the nature of the assemblages but principally is a measure of the lack of data from well documented Viséan assemblages.
>
> The presence of *Lycospora* species throughout is a characteristic of Viséan and younger assemblages and the apparently morphologically related species, *Cyclogranisporites tripapillatus* Staplin is known to occur in the Scremerston Coals of Northumberland and the lower levels of the Archerbeck Borehole. Reference to the assemblage details given below reveals the presence of other Viséan elements including *Didymosporites scotti* Chaloner, *Anapiculatisporites concinnus* Playford, *Glomospora lucida* Butterworth and Williams and *Schulzospora campyloptera* (Waltz) Potonié and Kremp. The virtual absence of *Tripartites* and *Rotaspora* is a striking feature of these assemblages which could be accounted for by either a too low stratigraphic position or an unusual ecological setting. The full significance of these assemblages must await the findings of additional studies.

The oldest miospore assemblages examined were obtained from an impersistent coal and its roof shales found near the base of the Crammel Linn Sandstone [6350 6810]. The coal seam yielded a well preserved but poorly diversified microflora in which *Calamospora spp.* and *Lycospora uber* Hoffmeister, Staplin and Malloy were dominant. *Glomospora lucida* (Plate XI, fig. 13), *Schulzospora rara* Kosanke and *S. campyloptera* were the only other species recorded, clearly representing the products of a specialized parent flora.

In the immediately overlying shales *Lycospora uber* becomes the dominant element in an association comprising *Waltzispora prisca* (Kosanke) Sullivan, *Reticulatisporites* cf. *cancellatus* (Waltz) Playford, *Microreticulatisporites concavus* Butterworth and Williams, *Densosporites bialatus* (Waltz) Potonié and Kremp, *Glomospora lucida*, *Schulzospora campyloptera* and *S. elongata* Hoffmeister, Staplin and Malloy. A single specimen of *Tripartites trilinguis* (Horst) Potonié and Kremp was also observed at this horizon, constituting the only record of this genus in the six horizons examined.

A thin coal and associated roof shales occurring between the Upper and Lower Millerhill Limestones [6858 7473] contained microfloras which are very similar to the lower horizon described above. The coal seam assemblage was dominated by *Calamospora spp.* and *Punctatisporites sp.* and that of the roof shales by *Lycospora uber*. In general terms the species recorded are common to both assemblages and include *Leiotriletes adnatus* (Kosanke) Potonié and Kremp, *Calamospora liquida* Kosanke, *Punctatisporites calvus* Staplin, *P. nitidus* Hoffmeister, Staplin and Malloy, *Didymosporites scotti*, *Granulatisporites piroformis* Loose, *Cyclogranisporites tripapillatus* Staplin, *Converrucosisporites sp.* (Plate XI, fig. 5), *Verrucosisporites* cf. *microtuberosus* (Loose) Smith and Butterworth, *V.* cf. *morulatus* (Knox) Potonié and Kremp (Plate XI, fig. 8), *Convolutispora sp.*, *Microreticulatisporites concavus*, *Lycospora noctuina* Butterworth and Williams, *Densosporites sp.*, *Knoxisporites gilleti* Doubinger and Rauscher, *Spinozonotriletes uncatus* Hacquebard, ?*Perotrilites sp.* (Plate XI, fig. 7), *Schulzospora campyloptera* (Plate XI, fig. 14) and *S. rara*. The species *Cyclogranisporites tripapillatus* is of especial interest in that it appears to possess an incipient cingulum, which when taken in conjunction with the three apical papillae, assumes a form which could be regarded as a primitive *Lycospora*.

In the assemblage isolated from the coal occurring 50 ft below the Appletree Limestone [6879 7282], *Cyclogranisporites tripapillatus* (Plate XI, figs. 3, 4) assumes the role of *Lycospora*, being abundant and completely dominating the diversified microflora, Other species recorded were *Retialetes radforthi* Staplin, *Chaetosphaerites pollenisimilis* Butterworth and Williams, *Leiotriletes politus* (Hoffmeister, Staplin and Malloy) Love, *Punctatisporites solidus* Hacquebard, *P. glaber* (Naumova) Playford, *Granulatisporites piroformis*, *Verrucosisporites sp.*, *Tricidarisporites balteolus* Sullivan and Marshall, *Lycospora uber*, *Densosporites spinifer* Hoffmeister, Staplin and Malloy, *Simozonotriletes priscus* Dybova and Jachowicz, *Vallatisporites vallatus* Hacquebard, and *Glomospora lucida*.

The coal seam which occurs between the Appletree and Leahill Limestones (6891 7252) contained a microflora poor in numbers of individuals and species. The assemblage was again dominated by *Calamospora spp.* and *Punctatisporites spp.*, in association with occasional specimens of *Micro-*

reticulatisporites concavus, *Convolutispora* cf. *ampla* Hoffmeister, Staplin and Malloy, *Densosporites bialatus*, *Lycospora uber* and *Schulzospora elongata*.

An abundance of densospores showing wide variation in ornament and cingulum structure distinguishes the two coals lying 15 ft [6905 7245] and 30 ft [6907 7244] above the Leahill Limestone. Several species have been recognized including *Densosporites spinifer*, *D. cuneicinctus* (Hoffmeister, Staplin and Malloy) Staplin (Plate XI, fig. 11), *D. aculeatus* Playford, *D. brachyacanthus* (Luber) Potonié and Kremp (Plate XI, fig. 12) and *D. spitsbergensis* Playford. The remaining species occurring in the two coals are as follows, *Chaetosphaerites pollenisimilis* (Plate XI, fig. 1) *Leiotriletes politus*, *Calamospora microrugosa* (Ibrahim) Schopf, Wilson and Bentall, *C. liquida*, *Punctatisporites glaber*, *P. stabilis* Playford, *Granulatisporites piroformis*, *G. dumosus* Staplin, *Anapiculatisporites minor* Butterworth and Williams, *A. concinnus*, *Apiculatisporis baccatus* (Hoffmeister, Staplin and Malloy) Butterworth and Williams, *A. spinosaetosus* Loose, ?*Verrucosisporites sp.* (Plate XI, fig. 9), *Verrucosisporites baccatus* Staplin (Plate XI, fig. 6), *Waltzispora lobophora* (Waltz) Staplin, *Microreticulatisporites microreticulatus* Knox, *Reticulatisporites* cf. *peltatus* Playford, *Corbulispora sp.* (Plate XI, fig. 10)

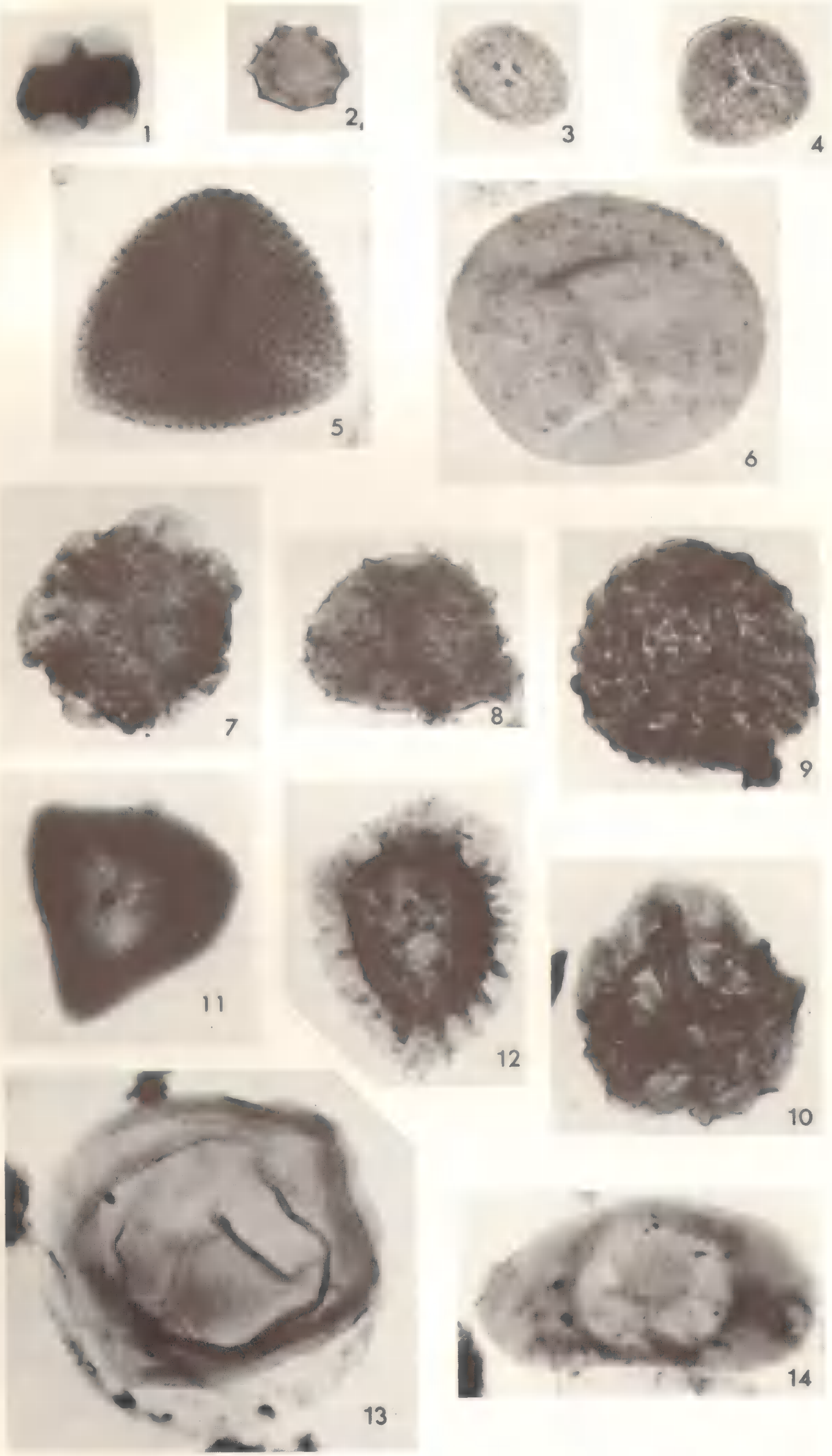
EXPLANATION OF PLATE XI

All figures magnification × 500. Figured specimens bearing the index letters MPK are stored in the collections of the Institute of Geological Sciences (Geological Survey), Leeds.

1. *Chaetosphaerites pollenisimilis* Butterworth and Williams. MPK 16. Coal 30 ft above Leahill Limestone, River Irthing [6907 7244].
2. *Incertae sedis*. MPK 17. Roof shale of coal near base of Crammel Linn Sandstone, River Irthing [6810 6350].

3, 4. *Cyclogranisporites tripapillatus* Staplin. MPK 18, 19. Coal 50 ft below Appletree Limestone, River Irthing [6879 7282]

5. ?*Converrucosisporites sp.* MPK 20. Roof Shale of Coal between Upper and Lower Millerhill Limestones, River Irthing [6858 7473].
6. *Verrucosisporites baccatus* Staplin. MPK 21. Coal 15 ft above Leahill Limestone, River Irthing [6905 7245].
7. ?*Perotriletes sp.* MPK 22. Roof Shale of Coal between Upper and Lower Millerhill Limestones, River Irthing [6858 7473].
8. *Verrucosisporites* cf. *morulatus* (Knox) Potonié and Kremp. MPK 23. Roof shale of coal between Upper and Lower Millerhill Limestones, River Irthing [6858 7473].
9. ?*Verrucosisporites sp.* MPK 24. Coal 30 ft above Leahill Limestone, River Irthing [6907 7244].
10. *Corbulispora sp.* MPK 25. Coal 30 ft above Leahill Limestone, River Irthing [6907 7244].
11. *Densosporites* cf. *cuneicinctus* (Hoffmeister, Staplin and Malloy) Staplin. MPK 26. Coal 30 ft above Leahill Limestone, River Irthing [6907 7244].
12. *Densosporites brachyacanthus* (Luber) Potonié and Kremp. MPK 27. Coal 30 ft above Leahill Limestone, River Irthing [6907 7244].
13. *Glomospora lucida* Butterworth and Williams. MPK 28. Coal near base of Crammel Linn Sandstone, River Irthing [6810 6350].
14. *Schulzospora campyloptera* (Waltz) Potonié and Kremp. MPK 29. Coal between Upper and Lower Millerhill Limestones, River Irthing [6858 7473].



SPORES FROM THE UPPER BORDER GROUP

Anulatisporites anulatus (Loose) Potonié and Kremp, *Lycospora uber*, *Simozonotriletes priscus*, *Schulzospora campyloptera*, *S. rara*, *S. elongata*, *Endosporites micromanifestus* Hacquebard and *Laevigatosporites minutus* (Ibrahim) Schopf, Wilson and Bentall.

LIDDESDALE GROUP

The lower part of the Liddesdale Group contains many fossils typical of the D_1 Zone. These include such corals as *Carcinophyllum vaughani* and *Lonsdaleia duplicata melmerbiensis*, and the brachiopods *Buxtonia sp. nov.* [Redesdale Ironstone Shale form with median ventral sinus—see Muir-Wood 1928, pl. 12, fig. 10], *Fluctuaria sp.*, *Gigantoproductus* of the *G. maximus* group, *Productus redesdalensis*, and *Punctospirifer redesdalensis*.

Among the reasons given by Lumsden and Wilson (1961) for assigning the Dinwoodie Beds to the base of the D_1 Zone was the fact that they are the lowest beds known to contain *Lithostrotion junceum*. In the Bewcastle district the lowest record of this species is in the shales overlying the Goat Island Limestone (loc. 96). It is worth noting that in the Bellingham district to the east (Sheet 13) the species occurs, along with other D_1 forms, in a limestone at Wood Park estimated to be some 1200 ft below the base of the Redesdale Limestone and the underlying Redesdale Ironstone Shale which have for many years been variously taken as marking the base of D_1 in the region (see Fowler 1966, p. 103). Similar evidence has been uncovered by Robinson (*in* Westoll and others 1955).

Higher in the group typical D_2 fossils are found, such as *Lonsdaleia floriformis* (in the Penton Limestone) and members of the *Gigantoproductus striatosulcatus* and *G. giganteus* groups. *Saccamminopsis fusulinaformis* is recorded only from the Buccleuch Limestone. The equivalence of part of the P_1 Zone and the D_2 Zone is confirmed by the occurrence of *Posidonia becheri* and *Beyrichoceratoides truncatus*? in the shales between the Gastropod and Tombstone limestones. In the higher limestones of the group are species which are elsewhere found in beds of P_2 age. They include *Avonia youngiana*, *Eomarginifera setosa*, latissimoid gigantoproductids, *Productus concinnus*, *Tornquistia polita* and *Weberides* with mucronate pygidia. However, goniatite evidence of the age of these beds is lacking and their P_2 age is presumed because of their position below the Catsbit or Great Limestone which is regarded as marking the base of E_1 (p. 222).

The Penton Linns section on the Liddel Water has provided a number of type specimens including those of *Euphemites pentonensis* (Weir) and *Edmondia pentonensis* Hind. W.H.C.R.

ALGAE

ENVIRONMENTAL SIGNIFICANCE

A study of Recent stromatolitic algal growths has been made by Logan, Rezak and Ginsberg (1962) which is a valuable contribution towards the understanding of the environmental conditions in which their fossil representatives flourished. These authors concluded that:

i. In protected intertidal mud flats where wave action is slight the algal growth form is that of a sheet of laterally linked hemispheroids as found in the fossil form-genus *Collenia*.

ii. In exposed intertidal mud flats where there is some scouring action by waves, growth between stromatolitic centres is prevented and a growth form of discrete, vertically stacked hemispheroids is developed as seen in the fossil form-genus *Cryptozoon*.

iii. In low intertidal areas exposed to wave action and in agitated shallow water below low water mark the algal growth form is that of a spheroid as in the fossil forms classed by Pia (1927) as Oncolithi (*Ottonosia*).

These three major classes of algal growth form are as useful as any for the generalized classification of fossil Stromatolites. A more detailed classification like that suggested by Logan, Rezak and Ginsberg, leads to some difficulty since all degrees of intergrading can be observed, at times all in the one specimen. Anderson (1950) attempted a form classification which was adopted by Johnson and Konishi (1956), in which the various growth forms were named after the form genera which they most closely resemble and Endo (1956) has advocated a similar scheme. But since the varieties of growth form are almost certainly determined by ecological factors they can have little systematic significance.

The factors controlling the development of the various growth forms were thought by Anderson (1950) to be:

i. The area of the colony in direct contact with water, i.e. the gas exchange area. This factor could lead to the development of the hemispherical form from the flat sheet in that the surface area would be increased relative to the area covered by the base. But the upward growth would be controlled by

ii. The light absorption area. In clear water the angle of incidence of light to the plant surface could be important. Doming of the surface would therefore have its limits and beyond a certain point the colony would tend to develop into a series of discrete pillars. In muddy water, where the light is diffused, nearness to the surface could be a more important factor.

Logan, Rezak and Ginsberg (1962) however have shown that scouring action by waves, which prevents growth between domes, is a contributing factor in the formation of columns, and it seems likely that the opposite situation, i.e. the accumulation of sediment between domes, would have a similar effect.

iii. Following from ii above, the rate of sedimentation is obviously an important factor and the rate of upward growth of the colony must exceed this if it is to survive. Thus the tendency to form hemispheroidal growth forms is probably present in all active colonies at moderate depth, sheetlike forms surviving only in areas of virtually no deposition. Where sedimentation is active upward growth into discrete pillars is probably the rule. Scouring action by waves in an area where pillars are being formed would normally produce columns in which the individual laminae do not curve down the sides.

iv. Stability. Algal sheets, though at first sight apparently the most resistant to disturbance by wave action, may well be the least so, particularly if they are subjected to periodic wetting and drying which in itself would tend to break up the crust. Breccias composed of broken up algal sheets are a common feature of algal deposits. Under present-day conditions Logan (1961) describes broken up algal mats as characteristic of the supra-littoral zone.

Tall columnar structures are also likely to be unstable and in agitated water the growth form is characteristically a spheroid built up of more or less concentric sheets the regularity of which depends on whether the growth developed from the beginning round a small regular nucleus or whether it was initiated on a broken fragment of a column and whether the rolling action of the current was regular or intermittent.

Though lime-secreting algae seem generally to grow more vigorously in warm rather than cold water their presence as fossils is not presumptive evidence of warm conditions. They have been recorded as forming calcareous crusts at about 64 degrees north latitude (Kindle 1935). *Lithothamnium*, which is a common associate of reef-building corals in tropical waters, is said to occur on the coast of Spitzbergen (Diener 1925) and is reported to be abundant on the coasts of Norway and northern Newfoundland (Twenhofel and others 1932).

All algae are holophytic, that is, they contain chlorophyll (Fritsch 1935), and are therefore unable to grow below the depth to which light will penetrate. In the north Atlantic algae rarely grow at depths greater than 30 metres (Smith 1938); and since the transparency of fresh water is much less than that of the sea it is a conservative estimate to say that algal reefs are not likely to have been formed below 30 metres in marine waters or below 10 metres in fresh water (Cloud 1942).

Stromatolitic growths offer no evidence as to salinity; they have been recorded living and fossil from both lake (Bradley 1927, 1929; Pia 1927; Johnson 1937; Kalkowsky 1908) and marine waters (Logan, Rezak and Ginsberg 1962; Black 1933; Anderson 1950; Garwood 1913b, 1914, 1916, 1931; Maslov 1935, 1937, 1939, etc.).

The Lower Carboniferous sediments of northern England and southern Scotland were, in the main, laid down in an algal environment and as will be seen in the sequel the type of growth form and associated sediments suggest conditions similar to those in which modern stromatolites are being formed, that is shallow water, in places littoral, generally sandy and rich in calcium carbonate, disturbed, often turbulent, rich in iron and silica.

SYMBIOTIC ASSOCIATIONS

Growths of filamentous algae are rarely composed of a single species or even genus. A radially growing form such as *Garwoodia* may be encrusted with or incorporate layers of a concentrically growing form such as *Girvanella*. Again several radial forms may grow together, for example *Garwoodia* is frequently associated with the smaller *Ortonella*. *Ortonella furcata* may have the finer growth of *O. kershopensis* amongst it, and in some cases also the still finer growth of *O. tenuissima*.

The association of serpulids with algal sops is so common as to suggest that algal growths provide an advantageous habitat for these worms even if the relationship is not strictly symbiotic.

SEDIMENTARY CHARACTERISTICS

Micrite. The form in which calcium carbonate is precipitated by calcareous algae is characteristic. The calcite or aragonite is laid down in the form of rounded granules of average diameter 0·1 mm, usually dark coloured because of the inclusion of organic matter, and bound together by a thin gelatinous coat.

The resulting rock, micrite, is a limestone with a cryptocrystalline or finely granular texture. This texture may be uniform, but is more commonly banded with coarser, more open layers alternating with finer and denser layers. A flocculent appearance, resulting from a tendency for the granules to form aggregates, is not unusual and a type of banding is often seen in which dense evenly textured micrite alternates with flocculent layers. Since the calcareous masses produced by the growth of calcareous algae both living and fossil are made up of this material, micrites may be suspected to be algal deposits although no trace of the algal filaments remains.

Many micrites are cavernous, the cavities being filled with a mosaic of clear calcite crystals about 0·3 mm in diameter, but up to 1·0 mm in veins. It is thought that this calcite was inorganically precipitated prior to the consolidation of the micrite mud since the boundaries of the mosaic are generally indefinite and the process of crystallization caused no visible disturbance of the micrite.

Micrites, however, appear to have been particularly prone to recrystallization commonly by dolomitization forming a mosaic of crystals generally 0·04 mm diameter, and since this process took place after consolidation, structures in the micrite are destroyed and the resulting mosaic is usually loaded with organic dust. Many of the bands of algal growth remain clearly outlined by layers of dust in the mosaic ('dirty mosaic' in the detailed account which follows) although all trace of algal filaments has been destroyed. Subsequent dolomitization generally destroys even the pattern of the dust layers since by this process inclusions in the calcite crystals are pushed out to the crystal faces.

Pellets and Ooliths. Some of the commonest forms of algal limestone are the 'pellet' beds. These consist of more or less rounded fragments of micrite in a matrix of calcite mosaic, micrite or a mixture of both. They range from limestones which are essentially detrital, consisting entirely of derived material although much of this may have been algal in origin, e.g. pellets or pebbles of micrite, shell fragments and quartz grains deposited in a non-algal environment, to beds of pellets in a matrix which includes contemporary algal growths (see Plate X).

These micrite pellets are spheroidal, ovoid or sausage-shaped and frequently contain traces of algal filaments. They are thought to be the remains of a thin algal crust which has been broken up by wave action, the fragments having been rolled before being incorporated in a later deposit. Pellet beds are therefore analogous to a conglomerate. Algal breccias in which the fragments of crust are unworn and angular are more commonly found in the coarser detrital deposits.

True oolites are rare in the Bewcastle sediments, and rocks generally referred to as oolites are usually pellet beds with a proportion of oolitic grains admixed. The distinction between pellets and ooliths is easy to define, but difficult to draw. A truly oolitic concretion is nearly spherical and consists of concentric layers of acicular crystals arranged radially within each layer. Nodular algal growths such as those sometimes formed by *Garwoodia* may also be sub-spherical, made up of concentric layers, each layer having a radial structure, but in this case each layer is formed by the growth of radial tubules. *Girvanella* nodules are also built up of concentric layers, but in this case each lamina is formed by filaments which grew concentrically. Probably a true oolith is formed inorganically by precipitation round a nucleus in water sufficiently agitated to keep the growing oolith in constant motion, though there is reason to believe that some organic material which may be algal is necessary to act as a binder. Algal nodules must be formed in a similar situation in order that growth may take place equally on all sides. In the Bewcastle sequence a combination of organic and inorganic precipitation of calcium carbonate is the most usual. In the pellet beds algal fragments predominate either uncoated or with an envelope of radial calcite (tufa). In the ooliths the nucleus is usually a pellet which has a thick deposit of radial calcite round it. All degrees and combinations are found, including alternating layers of micrite and tufa, so that any distinction is purely arbitrary and hence the noncommittal term 'algoolite' has been used throughout much of this memoir. Even the reverse arrangement is occasionally seen, that is, an oolith, sometimes two or three, surrounded by a micritic coat. Again, a micrite pellet may be surrounded by a later algal growth which in turn is coated with tufa. In thin section the distinction is clearly marked, the micrite is usually dark and frequently structureless whilst the tufa is pale yellow or translucent with a clearly defined radial structure.

Recrystallization commonly adds another complication, since there appears to be a tendency for spheroidal algal growths to be altered to radially crystalline calcite. In this case, however, the original laminae are usually preserved as dust layers or shadows and the calcite is generally full of fine organic debris.

Finally, a distinction can be made between algal limestones which are purely detrital, in which all the algal material is derived either in the form of pellets or as fragments of algal sops, and limestones which, though primarily composed of derived material, were yet formed in an algal environment as is shown by growths *in situ* either as individual sops or as encrusting layers around shell fragments, or by the presence of shells bored by algae. A third type is the true algal reef which is primarily composed of algal material grown *in situ* even though there may be a considerable amount of detritus accumulated between the sops usually in the form of ostracod shells and quartz grains. However, these large algal growths are much more common to the east and north-east in north Northumberland and along the Scottish border into Berwickshire. This suggests that the Bewcastle area was well away from the shoreline though at times the water must have been very shallow, and that wave action was in general little more than a gentle oscillation.

There is frequent intergrading even in the same bed of limestone; a common type in the Main Algal Series is one in which algal sops are embedded in a micrite full of pellets and ostracod shells, usually with some detrital or authigenic quartz and irregular cavities filled with a clear calcite mosaic.

The detrital quartz in the limestones is remarkably uniform in size generally, grains being about 0·06 mm long. There are several instances of secondary growth in optical continuity forming crystals up to 0·2 mm in length. This is clearly a post-consolidation phenomenon as the new growth can be seen to penetrate 'ooliths' the concentric structure of which is still clearly visible outlined in fine dust in the quartz. Authigenic quartz grains found in four of the limestones are assumed to be a penecontemporaneous addition since the crystals are sometimes enveloped in micrite or in algal growth.

Serpulids are common and are often found attached to the outer surface of a sop or in layers within it. Foraminifera, crinoid debris, shell fragments other than ostracod, and bryozoa are more common in the detrital algal limestones than in the reefs.

Sequence of Algal Limestones

LYNEBANK BEDS

In Ellery Sike the lowest limestone in the Lynebank Beds is a massive shelly detrital limestone showing no evidence of contemporaneous algal activity.

Separated from it by a few feet of shale, the next limestone above is Garwood's 'Lowest Algal Reef'. In exposures in Ellery Sike and in the River White Lyne this is a bed largely made up of ostracod shell fragments in a dark-brown micrite and containing algal sops. It includes irregular cavities filled with calcite mosaic (crystal diameters ranging from 0·04 to 0·15 mm diameter) and there is much authigenic quartz (crystals averaging 0·15 mm diameter). The algae represented are *Aphralysia carbonaria*, ?*Bevocastria conglobata*, *Garwoodia gregaria*, *Ortonella furcata* and *O. kershopensis* all growing *in situ*.

One typical spherical growth consists of a central mass of *Garwoodia* surrounded by a layer of mixed ?*Bevocastria* and *O. furcata*, then by a second layer of *Garwoodia* again followed by ?*Bevocastria* and *O. furcata* and by a third layer of *Garwoodia* followed by *O. kershopensis*, next a layer mainly of *O. furcata*, the whole surrounded by a loose-textured growth of ?*Garwoodia* and ?*Bevocastria*.

The Lower Worm Bed of Garwood (1931) lies only a short distance above and is a similar micritic limestone, but it is richer in iron oxide. Serpulid tubes and micrite pellets are abundant but the algal growth is poor and only a little *O. furcata* was seen.

The two thin limestones above do not appear to be algal but a higher thin limestone, approximately half-way between the 'Lowest Algal Reef' and the Ellery Sike Limestone in the River White Lyne, is a mixture of dark granular micrite and calcite mosaic (crystals averaging 0·06 mm diameter) heavily impregnated with iron oxide, with some detrital quartz (grains averaging 0·1 mm diameter), serpulid tubes and shell fragments—mainly ostracod. It contains well-preserved and abundant growths of *O. furcata* with some *O. kershopensis* Most of the sops appear to have grown *in situ* but some are brecciated.

Another serpulid limestone underlies the Ellery Sike Limestone. This is Garwood's 'Upper Worm Bed' and is similar to the 'Lowest Algal Reef', in that it is a mixture of micrite and calcite mosaic with much authigenic quartz, serpulids and with some *O. furcata*.

The Ellery Sike Limestone (*Pustula interrupta* Limestone of Garwood) is a partly dolomitized mixture of dark micrite and calcite mosaic (crystals averaging 0·04 mm diameter) with a little detrital quartz (grains averaging 0·04 mm in length) and some ostracod shell fragments. Nodular algal growths are common particularly towards the base of the limestone. The algae are mainly *Girvanella staminea* and *G. wetheredii* encrusting shell and crinoid stem fragments.

In the River White Lyne this limestone contains *O. furcata* and *O. kershopensis* in addition to *Girvanella* and all appear to have grown *in situ*.

At a position about 20 ft above the Ellery Sike Limestone and 30 ft below a bed of breccia is a bed of shelly limestones which contains poorly preserved *Girvanella* and *Ortonella* at outcrop in Bothrigg Burn. It is a brown granular micrite with patches of fine-grained calcite mosaic (crystals about 0·06 mm diameter) and contains ostracods, serpulids, some detrital quartz (grains about 0·10 mm in length) and much authigenic quartz. Some of the ostracod fragments are enclosed in pellets of micrite.

The next three limestones in upwards sequence are shelly and detrital, with no evidence of algal remains, but thin bands of 'oolite' above and below the Rawney Tuff in Bothrigg Burn mark the beginning of another algal phase. The lower band is a calcite mosaic (crystals about 0·1 mm diameter) containing much detrital quartz (grains about 0·06 mm long), some of which shows secondary growth, and with bands and patches of dark ferruginous micrite. No algal remains could be recognized but the manner in which the sand grains and shell fragments are coated with micrite suggests that the environment was algal. The upper band is less sandy and is an algoolite in which the micrite is mostly in the form of pellets. *O. furcata* may be present but the preservation is poor.

The Rawney Limestone shows a rich algal development in which *G. ducii*, *G. wetheredii*, *O. furcata* and *O. kershopensis* form spherical growths up to 1 cm in diameter. The sops are set in a matrix of micrite full of shell fragments, mainly ostracod, with serpulids, rather coarse detrital quartz (grains about 0·2 mm) and some micrite pellets. In Bothrigg Burn *G. nicholsoni* is also present.

The Common Flat Limestone is only partly seen in the River Black Lyne (p. 20) where it is dark and limonitic, and is composed of small rounded pellets and scattered 'oolites' of much larger diameter set in a matrix of flocculent micrite, but with patches of calcite mosaic (crystals about 0·3 mm diameter). There is much detrital quartz (grains about 0·1 mm in length) some of which shows secondary growth. Many of the pellets are fragments derived from an earlier pellet limestone which also contained some detrital quartz. The Common Flat Limestone therefore appears to have been largely built up of material derived from a previous algal deposit and the only determinable algae (*O. furcata*) were in these derived fragments.

In the River Black Lyne several limestones occur in the 420 ft between the Common Flat Limestone and the top of the Lynebank Beds. In the lower half of this sequence the limestones are either formed by masses (usually sandy) of serpulid tubes and ostracod shells, or they are pellety and 'oolitic' (algoolitic), with ostracods and with detrital quartz showing secondary growth. Their history is complex, involving first the formation of a thin sheet by more turbulent water carrying sand grains, the fragments then being rolled into pellets some of which became coated with tufa. Later, the growths of algae caused some of these pellets and 'ooliths' to be bound together by the micrite deposited round them, the only evidence of algal conditions at this stage being the poorly preserved remains of *Girvanella*. Probably also at this stage, secondary growth on the sand grains produced idiomorphic crystals which commonly penetrate, but do not distort the 'ooliths'. Finally the crystallization of calcium carbonate from the surrounding water bound the mass of pellets within a calcite mosaic.

In the upper part of the sequence especially where exposed in Kirk Beck, the limestones are shelly, with *Antiquatonia teres*, gastropods and ostracods. In the Black Lyne sequence micrite pellets are still abundant and there is detrital quartz some of which shows secondary growth. Determinable algal remains are rare and are generally found in the derived pellets and not in the matrix.

BEWCASTLE BEDS

The Bogside Limestone at the base of the Bewcastle Beds as seen in the Black Lyne is a thick detrital limestone with abundant *A. teres* similar in type to those near the top of the Lynebank Beds below. About 12 ft above is a thin, grey, fine-grained, pyritic limestone largely composed of ostracod shell fragments and serpulid tubes in a calcite mosaic (crystals about 0·2 mm diameter).

There are small scattered micrite pellets and some detrital quartz (grains about 0·08 mm long), commonly showing secondary growth. The environment was algal as is shown by the ostracod shells of which some are bored by algal filaments and others contain, or are encrusted by, dark micrite containing algal tubes (*O. kershopensis* and ?*Garwoodia*).

A thin limestone 12 ft higher in the sequence is different, being composed of pellets in a calcite mosaic (crystals about 0·16 mm diameter). A few of these pellets which range from about 0·1 to 0·6 mm in diameter, are more or less spherical, but most are bean- or sausage-shaped. The centre is usually an ostracod shell fragment, which is surrounded by a coating of micrite outside of which is a layer of tufa. There is some detrital quartz (grains about 0·15 mm long) some of which shows secondary enlargement and also some authigenic quartz. The rock contains much spherulitic iron and is partially dolomitized. The environment was algal, *G. wetheredii* and *O. furcata* were both seen in micrite fragments and *G. ducii* was present as an encrusting growth. Again the rock appears to have been largely composed of material derived from the break-up of a pre-existing algal crust. *Bevocastria conglobata* occurs at this horizon in the Hole of Lyne sequence (p. 30), which is Garwood's type locality for *Bevocastria.*

The Kitty Beck Limestone some 30 ft above, is also a mass of micrite pellets cemented by a calcite mosaic (crystals about 0·04 mm diameter). Many of the pellets show clear evidence of their algal origin containing *O. kershopensis* and fragments of *Gymnocodium sp. nov.*, and a sop, apparently grown in place, of *O. furcata* shows that the environment too was algal. There is abundant detrital quartz (grains about 0·02 mm long) many grains of which appear to have been shattered and then recemented by calcite *in situ.*

Two thin limestones, about 15 and 48 ft above the Holmehead Limestone, are largely composed of shell fragments in a mixture of micrite, calcite mosaic (crystals about 0·02 mm diameter) and dolomite (crystals about 0·04 mm diameter) and are heavily veined by calcite (crystals about 0·02 mm diameter). They contain a little detrital quartz (grains ranging from 0·05 to 0·15 mm in length). Calcispheres are common and traces of *Girvanella wetheredii* and *O. furcata* can be seen in the micrite of the matrix.

A few feet higher in the sequence the next limestone, exposed in Bailey Water, is similar to those below, being mainly composed of shell fragments, but with micrite pellets, many of which show evidence of having been derived from an algal crust composed of *G. wetheredii* and *O. furcata.* Detrital quartz (grains about 0·1 mm long) is more abundant than in the limestone below and some show secondary growth.

The New House Limestone, which overlies the Parkhead Sandstone in Bailey Water, is a partly dolomitized dark grey limestone composed of more or less rounded fragments of micrite set in a matrix of calcite mosaic (crystals about 0·04 mm diameter). There is some detrital quartz (grains about 0·2 mm long) and both the quartz grains and pellets are coated with a thin layer of iron oxide. In one zone the pellets are crushed together and show irregular solution outlines. One pellet is a fragment of a sop of *Ortonella furcata* but apart from this algal filaments are rarely seen. The rock is traversed by thin calcite veins in which the crystals (about 0·4 mm diameter) lie normal to the sides of the veins. This limestone appears to have been constituted from fragments of a hard algal crust, pellets of soft algal mud, ostracod and other shell fragments in an iron-rich environment subsequently cemented by crystalline calcium carbonate, some of which was later altered to dolomite. Finally, the rock was shattered and the cracks filled with vein calcite.

In the River Black Lyne the Earthworks Sandstone is succeeded by a group of four limestones, the highest named the Ashy Cleugh Limestone. All are similar in that they consist largely of micrite pellets (from 0·15 to 0·66 mm in diameter) in a calcite mosaic (crystals ranging from 0·02 to 0·15 mm diameter). There is some detrital quartz (grains from 0·04 to 1·0 mm long) often showing secondary growth and a little authigenic quartz (crystals about 0·045 mm long). Ostracods and serpulids are common; many of the former were partially filled with micrite before being incorporated in the limestone, since their present orientation is random. Some of the pellets contain algal filaments including *Garwoodia* and *Ortonella*, and there are fragments of *?Gymnocodium*.

The growth of the quartz grains appears to be a post-consolidation phenomenon since the extensions penetrate their micrite envelope and even adjacent shell fragments without moving or distorting them.

The Rigghead Limestone, as seen in Green's Burn, includes micrite pellets and abundant serpulids with quartz grains about 0·15 mm long. One gastropod shell is surrounded by a radial growth of *O. furcata* and *O. kershopensis* in layers separated by concentric sheets of *G. ducii* and *?G. nicholsoni*. The inside of the shell is filled with dark micrite which contains a little detrital quartz (grains about 0·06 mm long).

The Stack Cleugh Oolite, as seen in Stack Cleugh (p. 40) consists of a matrix of granular micrite closely packed with micrite pellets (about 0·1 mm diameter) and 'ooliths', serpulids and shell fragments, many of which are coated with micrite. There is a fair amount of detrital quartz (grains about 0·1 mm long) some of which shows secondary growth.

The Peel Limestone is a mixture of dark and pale-coloured flocculent micrite and a little calcite mosaic (crystals about 0·15 diameter) with micrite pellets, 'ooliths', ostracods and other shell fragments. The dark micrite which contains poorly defined algal tubules appears to be all in the form of angular fragments and is therefore probably derived from a broken algal crust, whilst the pale micrite, also algal and containing some *Garwoodia gregaria*, forms the matrix for both the unworn fragments and the rolled pellets. There is a little detrital quartz (grains about 0·2 mm long), some of which shows secondary growth.

The lower leaf of the Junction Limestone in Green's Burn and in a swallow hole near Borderrigg Farm, is a dolomitized mudstone. It is made up of a mixture of fine dolomite mosaic (crystals about 0·02 mm diameter) and a coarser dolomite (crystals 0·1 mm diameter) with a little detrital quartz (grains about 0·06 mm long), and abundant serpulids which are filled with a coarse calcite mosaic (crystals up to 1·0 mm diameter). The upper leaf is composed of 'ooliths' and micrite pellets in a calcite mosaic (crystals about 0·2 mm diameter), with some patches of dolomite (crystals about 0·04 mm diameter), and with ostracod shell fragments, some of which are bored by algae.

MAIN ALGAL BEDS

Crookburn. The lowest of the Main Algal Beds (MA 1) is a dolomitized fragmental limestone, with serpulids, bryozoa and crinoid fragments and with detrital quartz (grains 0·09 mm long); it is very ferruginous. At the base and top are layers of micrite pellets, generally less than 0·3 mm in diameter, in a matrix of crystalline calcite (crystals about 0·05 mm in diameter). Calcispheres are abundant and there are some ostracod shell fragments and crinoid stems. These layers are sandy (grains about 0·075 mm long) and appear to have been deposited in an algal environment, though only poorly preserved fragments of *Garwoodia* (or *Ortonella*) were seen.

A thin limestone about 2 ft above MA 1 is a secondary dolomite (crystals from 0·015 to 0·09 mm in diameter) with cavities filled with calcite mosaic (crystals up to 0·3 mm diameter) and a little detrital quartz (grains about 0·03 mm long). Originally the rock appears to have been a shelly calc-mudstone. Main Algal Three (MA 3) is composed of irregularly shaped micrite pellets set in crystalline calcite (crystals 0·06 mm diameter), with serpulids and some detrital quartz (grains about 0·08 mm long). Amongst the pellets are fragments of algal growth including *O. kershopensis*, common and well preserved, and *O. tenuissima*. Main Algal Four (MA 4) is largely composed of shell fragments especially in the upper half. The lower part includes many micrite pellets about 0·4 mm in diameter some of which simulate ooliths. The pellets, 'ooliths' and micrite fragments, probably all derived, contain abundant algal remains which include *G. ducii*, *Koninckopora inflata*, *K. tenuiramosa* and *O. furcata*. The environment was algal, for some of the shell fragments in the upper part of the limestone have been enveloped in a growth of *O. kershopensis* and *G. ducii*.

The Birky Cleugh Limestone is shelly, pellety, full of serpulids and contains a rich algal flora. Shell fragments are encrusted with *Bevocastria conglobata*, *G. ducii*, *O. furcata*, and *O. kershopensis*, and some are bored by algae. There is a little detrital quartz (grains 0·10 mm long) ostracods, fish scales, crinoid stems, bryozoa and foraminifera. The top of this limestone is very sandy.

The next limestone in sequence (MA 7) is a thin band of 'ooliths' set in a crystalline calcite mosaic (crystals about 0·15 mm diameter). The 'ooliths' are about 0·5 mm in diameter, are mainly spherical and are not in contact. Many show a very fine concentric structure and some are definitely built up of concentric growths of *Girvanella*, though the smaller ones tend to be ovoid and structureless. The centres are commonly formed by sand grains. This is important in that it demonstrates quite clearly that some of these oolitic bodies are algal structures. The author has long suspected that the majority of these so-called oolites in the Lower Carboniferous rocks were algal in origin (algoolites), but it is rarely possible to detect any trace of algal filaments in them. The association of oolitic bodies and algal growths is commonplace, but this is not necessarily evidence of their algal origin since the environmental conditions, i.e. shallow disturbed water and a high calcium carbonate concentration, are those which favour the development of both algal spheroids and inorganic concretions such as ooliths.

The overlying limestone (MA 8) consists mainly of ovoid pellets ranging from about 0·3 mm to 0·7 mm in length in a matrix consisting of irregular masses of granular micrite and patches of calcite mosaic (crystals about 0·08 mm across) containing a fair amount of detrital quartz (grains about 0·9 mm long). The pellets show very fine concentric structure, but also some radial crystallization which may be secondary, and tend to lie with their long axes parallel. Their centres are usually quartz grains or ostracod shell fragments. Some have a dense outer layer about 0·015 mm thick. There are several examples of pairs of ooliths enclosed in a common outer coat of micrite. No algal remains have been detected in the pellets themselves, but traces of branching tubules were seen in the micrite areas of the matrix, which also contained serpulids and ostracods.

The Main Algal Reef of Garwood is one of a group of ten limestones. There is some faulting at this horizon in Crookburn and these limestones are better seen in Birky Cleugh.

Birky Cleugh. The basal limestone (MA 1) in Birky Cleugh, like that in Crook Burn, is a patchily dolomitized ferruginous detrital limestone with micrite pellets, some of which are tufa-coated, at top and bottom. There is a little detrital quartz (grains about 0·06 mm long) and in some of the pellets and micrite fragments the sand grains show secondary growth. One shell fragment is encrusted with *G. wetheredii* and suggests that the environment was algal at the time of deposition, but it is evident that most of the 'ooliths', pellets and micrite fragments, were derived from pre-existing oolitic, pellety algal limestones. At least one of these earlier limestones contained *O. furcata* and *O. tenuissima*, another serpulids and a third euhedral quartz grains.

Main Algal Two (MA 2) is a ferruginous detrital limestone largely made up of ostracod shell fragments and some serpulids, but with pellets of dense micrite and 'ooliths' and a little detrital quartz (grains about 0·085 mm). Probably all the pellets and 'ooliths' were derived and re-deposited in an algal environment since many of the 'ooliths' are tufa-coated and occasional pellets carry an encrusting layer of *G. ducii*. Some of the 'ooliths' are composed of *Ortonella tenuissima* and there are fragments of micrite enclosing *G. ducii* and *O. kershopensis* and commonly two or more 'ooliths'. Many 'oolith' nuclei are quartz grains showing secondary growth.

The thin limestone between MA 2 and MA 3 is made up of abundant ostracod shell fragments, pellets and 'ooliths' in a micrite matrix. There is a little detrital quartz (grains about 0·07 mm long). Again the evidence indicates that this is an accumulation of algal limestone detritus deposited in an algal environment; some of the pellets contain *G. wetheredii*, others are tufa-coated and some of the shell fragments are encrusted with *O. kershopensis.*

Main Algal Three (MA 3) is here a dense micrite full of serpulid tubes. Inside these tubes the original calcareous mud was generally protected from compression and is preserved as a loose flocculent micrite or by a clear calcite mosaic.

The overlying limestone (MA 4) is composed of sub-spherical pellets and angular fragments of micrite in a matrix of paler, less dense and in places cavernous micrite, the cavities being filled with microcrystalline calcite. No algal filaments have been seen in the matrix, but many of the derived pellets are worn fragments of *G. ducii* sops, and some of the 'ooliths' appear to be composed of *O. tenuissima*. Fragments of *Koninckopora* and *Garwoodia* are also present.

The Birky Cleugh Limestone is, at the base (MA 5), a fine-grained calcareous sandstone (quartz grains about 0·12 mm long) containing many shell fragments, mainly ostracod, and micrite fragments, some of which contain *Garwoodia* and *Girvanella wetheredii.* Above it becomes a dense micrite with much detrital quartz (grains about 0·10 mm long), ostracods, shell fragments and spheroidal growths of *Garwoodia gregaria* about 7·5 mm in diameter. There are also micrite pellets containing *Girvanella ducii*, *G. wetheredii*, and 'ooliths'. Though the pellets were derived from a broken up algal crust, most of the algae found in this limestone appear to have grown *in situ*. The sops of *Garwoodia* are complete, *Ortonella kershopensis* and *O. furcata* occur in the matrix and some of the pellets and micrite fragments are encrusted by a growth of *Girvanella wetheredii*, and *G. ducii*. This is a typical algal development in a low inter-tidal area in which the oncolithic form of algal growth is favoured. At a slightly higher level in the Birky Cleugh Limestone pellets and fragments of micrite occur in a clear mosaic (crystals 0·1–0·2 mm diameter). These fragments, derived from an algal crust, contain *Garwoodia gregaria* and some are encrusted with *Girvanella wetheredii* and *O. kershopensis*. The topmost part (MA 6) of the Birky Cleugh Limestone was not sectioned. Main Algal Seven (MA 7), which lies about 7 ft higher in the sequence, is represented by calcareous sandstone containing algal nodules too poorly preserved for identification. The next limestone above (MA 8) is 8½ ft thick and includes Garwood's 'Oolite Band'; at the base it is made up of a mass of micrite pellets many with a heavy coating of iron oxide, in a calcite micromosaic (crystals about 0·02 mm diameter). Some of the pellets contain algal filaments (*Garwoodia gregaria* and *O. kershopensis*). The algal crust from which these pellets were derived was probably not more than 0·2 mm thick since most of the pellets which average 0·45 mm in length are less than this in width. There are many ostracod shell fragments and some detrital quartz (grains about 0·1 mm long). The environment was algal since some of the fragments are coated with growths of *G. wetheredii*.

The succeeding limestone (MA 9), 9⅔ ft thick, is a mass of comminuted shell fragments, mainly ostracod, in a micrite matrix. There is a little detrital quartz (grains about 0·10 mm long).

A thin limestone rib between MA 9 and MA 10 is composed of ostracod and other shell fragments, with crinoid and bryozoan debris, in a matrix of brown micrite. Though algal growth forms are not seen, evidence of an algal environment is given by the fact that some of the shell fragments are penetrated by boring algae.

The 6-ft limestone forming the lower part of MA 10 is mainly composed of ostracod shell and crinoid debris in a matrix of cavernous micrite, the lacunae being filled with a calcite mosaic (crystals about 0·06 mm diameter). In this are algal bands and nodules made up of *Aphralysia sp.*, *Garwoodia gregaria*, *Girvanella wetheredii*, *G. ducii*, *Ortonella furcata*, *O. kershopensis*, and *O. tenuissima*. In addition many of the shell fragments are encrusted with algal growth. This bed represents a rich algal development in the low intertidal zone. The 2-ft cementstone at the top of MA 10 (p. 60) is a mass of shell fragments, ostracods predominating, with crinoid debris and bryozoan fragments (*Rhabdomeson sp.*), in a mixture of coarsely granular micrite and crystalline calcite (crystals about 0·03 mm diameter).

Main Algal Eleven (MA 11) is a 2-ft pellety limestone with sub-spherical algal growths up to 1·5 cm in diameter. In thin section micrite pellets, algal sops, abundant ostracods and much detrital quartz (grains about 0·04 mm long) are seen to be cemented by a patchy calcite mosaic (crystals about 0·04 mm diameter). Many of the pellets and in one case a sop of *Garwoodia*, are encrusted with *Girvanella wetheredii*. In another specimen a mass of *Bevocastria* is surrounded by *G. nicholsoni* outside of which is a crust of *G. wetheredii*. Other forms present include *G. ducii*, *O. furcata*, *O. kershopensis* and *O. tenuissima*. This rock was formed in a thoroughly algal environment as almost all the pellets are encrusted by algal growth.

Garwood's Main Reef (MA 12) is a shaly limestone with spheroidal algal growths averaging 3·3 cm in diameter. The matrix is a ragged mixture of micrite and calcite micromosaic with serpulids and ostracods. There is some detrital quartz (grains about 0·25 mm long) some of which shows secondary growth. The centre of a typical algal sop is formed of broken fragments of a sop of *O. furcata* with part of a sop of *O. kershopensis* attached and preserved in a very dark coloured micrite. This is enclosed in a matrix of dirty mosaic with ostracods, detrital quartz and shell fragments. This fragment of algal growth and matrix together constituted a pebble around which further algal growth took place, represented first by a layer of dense micrite with *O. kershopensis* followed by a layer of *Girvanella ducii*, then a second layer of *O. kershopensis* followed by a second layer of *G. ducii*, then a layer of *O. furcata* and an outer coating of *G. ducii*. This alternation of radial (*Ortonella* or *Garwoodia*) and concentric growth is a common feature in these spheroidal algal sops. Other algae found in this limestone are *Bevocastria conglobata*, *Garwoodia gregaria* and *Ortonella tenuissima*.

About 15 ft above the 'Main Reef' is an 8-ft serpulid limestone (MA 13) made up of alternating bands of coarse clear calcite mosaic (crystals about 0·3 mm diameter) and dark micrite. The micrite layers contain broken fragments of algal sops i.e. *Garwoodia*, *Girvanella ducii*, *O. furcata* and *O. kershopensis*. The rock appears to have been partly recrystallized.

Thin concretionary, possibly algal, limestone ribs follow in the 5 ft of shales above MA 13, but neither these nor specimens from MA 14 have been sectioned.

Crubinshill Sike. The lowest limestone seen in the faulted section of Crubinshill Sike (p. 47) is MA 11. The basal part of the bed consists of micrite pellets in a mixture of micrite and calcite mosaic (crystals about 0·09 mm diameter, but in places very coarse about 1·0 mm in diameter). There is some patchy dolomitization (crystals about 0·06 mm diameter). Ostracod shell fragments and serpulid tubes are abundant and as has been noted above, the micrite inside the serpulid tubes has remained uncompacted i.e. loose and flocculent. The pellets, some of which contain algal filaments (*G. ducii*, *G. wetheredii*, *O. furcata*, *O. kershopensis* and boring algae), were probably derived from a previously formed algal crust the rolled fragments of which, some coated with tufa, were deposited in an algal environment in which boring algae were active. There is some detrital quartz (grains about 0·10 mm diameter). The upper part of MA 11 is also a pellet bed, a mass of micrite pellets and shell fragments in a calcite mosaic (crystals varying from 0·03 to 0·6 mm in diameter). The pellets are sub-spherical to sausage-shaped and many show concentric banding. They rarely have a centre, but when they do it is usually a quartz grain or ostracod shell fragment. Some appear to have been corroded and have probably been derived. There is a little dolomite (crystals about 0·06 mm diameter) and some detrital quartz (grains about 0·08 mm long). The pellets occur in bands about one millimetre thick separated by an equal thickness of loose-textured micrite. Only traces of algal tubules are seen in the pellets, but the matrix contains sops of *Girvanella wetheredii*, *G. nicholsoni*, *G. sp. nov.*, *O. kershopensis* and boring algae, together with echinoid spines, ostracods and serpulids.

A few inches above this limestone is a thin calcareous band composed almost entirely of crushed and broken ostracod shells. There is a little detrital quartz (grains about 0·075 mm long).

Higher, another thin limestone above an 18-ft sandstone locally represents Garwood's 'Main Reef'. It is a shelly pellet bed with fragments of algal sops in a dirty calcite mosaic (crystals about 0·15 mm diameter), crowded with shell fragments and very dark micrite pellets. There is a little dolomite (crystals about 0·045 mm diameter), worn crinoid debris and some detrital quartz (grains about 0·07 mm long). The pellets show both radial structure and concentric banding. Pellets, shell and algal sop fragments all appear to be worn and were probably derived. But there are some indigenous algal growths including *Bevocastria sp.*, *G. ducii*, *G. wetheredii*, *O. furcata* and *O. kershopensis.*

The next limestone above (MA 13) is a pellet bed with algal sops in a calcite mosaic (crystals about 0·25 mm diameter); it is full of pellets and shell fragments, mainly ostracods. The pellets generally consist of worn shell fragments coated with micrite and with some interstitial tufa. Grains of detrital quartz (about 0·08 mm long), occur mainly in the pellet bands. One algal sop is composed of *Bevocastria* with *O. kershopensis* and there are many examples of boring algae. *Girvanella ducii*, *G. nicholsoni* and *O. furcata* are also present.

The highest limestone (MA 14) of the division is a thin shell bed with pellets and algal sops in a matrix mainly composed of dark coloured micrite, but with areas of a dirty calcite mosaic (crystals about 0·075 mm diameter) and some detrital quartz (grains about 0·08 mm long). Many of the shell fragments and pellets are encrusted with algal growth i.e. *Bevocastria*, *G. ducii*, *O. furcata*, *O. kershopensis and O. tenuissima.*

CAMBECK BEDS

The lowest algal horizon in the Cambeck Beds is in the top of the Barron's Pike Sandstone. As seen in Show Burn (p. 74) it comprises 2½ ft of ferruginous sandy limestone containing spheroidal algal sops. In thin section it is seen to consist of a mixture of dark micrite and hematitic dolomite mosaic (crystals about 0·04 mm diameter), but with cavities filled with a clear calcite mosaic (crystals about 0·2 mm diameter). There is much detrital quartz (grains about 0·2 mm long) and many corroded shell fragments, crinoid stems and ostracods. The following algae were recognized: *Garwoodia gregaria*, *Girvanella ducii*, *G. staminea*, *Koninckopora inflata*, *O. furcata*, *O. kershopensis* and boring algae.

The succeeding thin limestone, which lies near the base of the Upper *Antiquatonia* Band, appears to be entirely detrital, with no evidence of algal activity, but the 2 ft of ferruginous sandy limestone somewhat higher in the Upper *Antiquatonia* Band in the White Lyne contains algal sops. This rock is a calcite mosaic (crystals about 0·2 mm diameter), with much detrital quartz (grains about 0·2 mm long), crinoid stems and echinoid spines, shell fragments and ostracods. *Garwoodia* and *O. furcata* are present, apparently in the position of growth.

A few feet above is another thin detrital limestone followed by a partly dolomitized shelly limestone which contains small micrite pellets, but no recognizable algae. As seen in a small stream near Gillalees Farm this rock is a ferruginous micrite full of scattered dolomite crystals, small shell fragments, crinoid debris, bryozoan fragments, productid spines, fish debris and detrital quartz (grains about 0·1 mm long).

The highest and thickest of the limestones of the Upper *Antiquatonia* Band is shelly and detrital as are the next six limestones above, including representatives of the Maidenway and Butt Limestones. The Maidenway Limestone is best seen, however, in a small stream near Spadeadam Farm, where it is sandy (grains about 0·2 mm long), locally dolomitic (crystals about 0·02 mm diameter) and crowded with spherical sops of *Garwoodia* up to 4·5 cm in diameter (see p. 77).

The Whiterigg *Serpula* Band, as seen in a stream 500 yd due west of Spadeadam Farm (p. 77) is composed largely of algal pellets and shell fragments in a calcite mosaic (crystals about 0·06 mm diameter) and with some detrital quartz (grains about 0·1 mm long), ostracods, serpulids and gastropods. *G. ducii*, *G. nicholsoni* and *O. furcata* appeared to be present but the rock is partly dolomitized and the preservation is poor.

The next limestone above is detrital and contains no evidence of algae but above this in the River White Lyne is a 30-in limestone consisting of a ferruginous dolomite mosaic (crystals about 0·04 mm diameter), pale micrite, a little detrital quartz (grains about 0·04 mm long) and indigenous growths of *Girvanella ducii*, *G. staminea*, *G. wetheredii* and *O. furcata*. In Cam Beck this limestone contains many serpulid tubes and some micrite pellets and the quartz is a little coarser (grains about 0·08 mm long). Here *G. ducii* is common, with *O. furcata* and *O. tenuissima*.

The *Syringothyris* Limestone and the thin limestone above it do not appear to be algal but the two limestones with intercalated shale which comprise the Hillend Algal Band have a rich algal flora. In Cam Beck, west of Parkgate Bridge (p.79), the lower of the two limestones is a mass of closely packed sops of *Garwoodia* up to 1·5 cm in diameter in a matrix partly of micrite, with detrital quartz (grains about 0·1 mm long) and minute shell fragments, partly of a clear calcite mosaic (crystals about 0·2 mm diameter, secondary) and partly of a dirty calcite mosaic (crystals about 0·1 mm diameter, ?re-crystallized, primary). *Girvanella ducii*, *G. nicholsoni*, *G. wetheredii*, *O. furcata*, and *O. kershopensis*, are intergrown with the *Garwoodia* and *G. staminea* is commonly seen encrusting the outside of a sop. In some cases the *Girvanella* filaments can be seen wrapped round the *Garwoodia* tubules. *O. furcata* also forms independent sops and there are some boring algae. In Show Burn the limestone contains *Koninckopora inflata* in addition to *G. ducii* and *O. furcata*. In Whitberry Burn the algal development is equal to that in Cam Beck. The spheroidal *Garwoodia* sops about 1 cm in diameter are in a matrix of micrite with some calcite mosaic (crystals about 0·1 mm diameter) and some detrital quartz (grains about 0·07 mm long), micrite pellets and ostracod shell fragments. Typically the *Garwoodia* sops are coated with a growth of *Girvanella wetheredii* and have an interstitial growth of *O. furcata*, *O. kershopensis* and *O. tenuissima*. There are also good examples of *Aphralysia*. In the White Lyne this horizon is marked by a 33-in limestone very like those described above, but the preservation is poor. *O. furcata* appears to be more common than *Garwoodia*.

The next limestone above, as seen in Show Burn, may also be algal. It is a mass of broken partly worn fragments of micrite set in a mixture of flocculent micrite and calcite mosaic (crystals about 0·15 mm diameter) with a little

EXPLANATION OF PLATE XII

FIG. 1. *Semiplanus sp. nov.*, ventral valve, × 1. Upper Border Group. Appletree Limestone, River Irthing, [6897 7270]. HR 2256 See p. 171

FIGS. 2a 2b *Stenoscisma isorhyncha* (McCoy), lateral and anterior views, × 1. Upper Border Group, Middle Shield Beck. Garwood Collection GSM 68481 See p. 171

FIG. 3. *Buxtonia sp. nov.*, ventral valve, × 1. Upper Border Group, limestone below Appletree Limestone, R. Irthing [6374 6739]. Tm 303 See p. 171

FIG. 4. *Antiquatonia teres* (Muir-Wood), ventral valve, × 1. Lower Border Group, Cambeck Beds, Lower *Antiquatonia* Band. Birky Cleugh [5932 7539]. HR 2258 See p. 74

FIG. 5. *Dolorthoceras sp.* encrusted with algae. Thin longitudinal section, × 1·6. Lower Border Group, Main Algal Beds, M.A.11, Birky Cleugh [5923 7537]. HR 2257 See p. 169

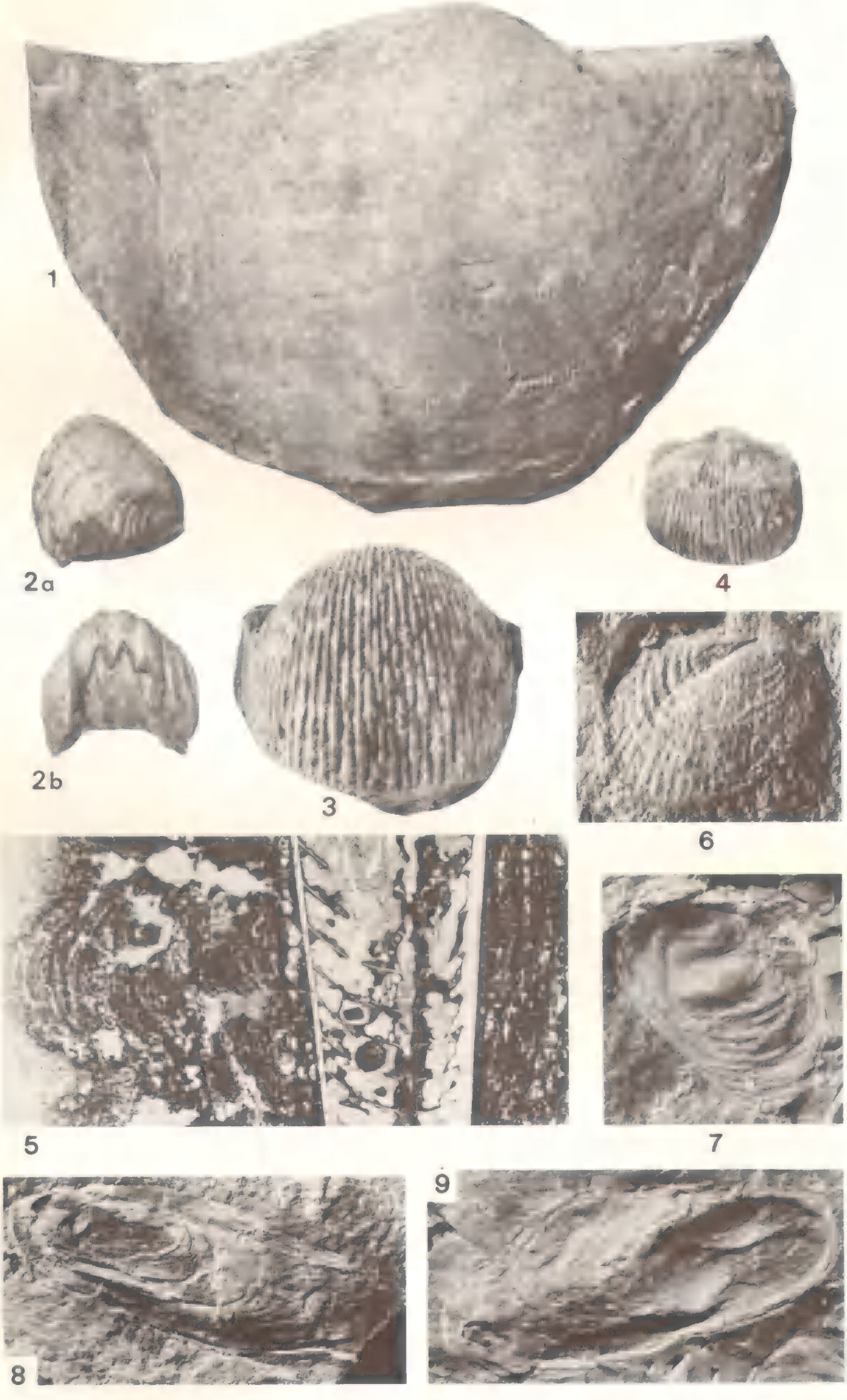
FIG. 6. *Anomalonema* [*Estheriella*] *defretinae* Novolijov, × 8. *Anthraconauta tenuis* Zone, Baxton Gill (Jockie's Sike) [4226 7569], 110 yd S.E. of mouth of stream culvert. V2268C See p. 227

FIG. 7. *Anthraconauta phillipsii* (Williamson), × 3. *A. tenuis* Zone, Liddel Water left bank [4257 7619] 210 yd S. of S.W. corner of Crookholm Farm. V 2497C. See p. 227

FIG. 8. *Anthraconauta tenuis* (Davies and Trueman), × 3. Horizon and locality as for Fig. 6. V 2273C See p. 227

FIG. 9. *Anthraconauta* cf. *wrighti* (Dix and Trueman), × 3. Horizon and locality as for Fig. 7. V 2497C See p. 227

The originals are housed in the Institute of Geological Sciences. Leeds.



CARBONIFEROUS FOSSILS

detrital quartz (grains about 0·06 mm long). There are obscure indications of algal tubules, but none are sufficiently well-preserved to identify.

The highest limestone in the Cambeck Beds lies a few feet above the last mentioned and is seen in Butter Burn. It is a granular micrite, partly dolomitized, with a little detrital quartz (grains about 0·04 mm long), numerous mainly ostracod shell fragments, crinoid debris, foraminifera and bryozoa. *Girvanella wetheredii* can be recognized, but in general the algae are too badly preserved to be identified. F.W.A.

LIST OF FOSSILS

The numbers given after each species correspond to the locality numbers given in the list of the localities on p. 199.

Lower Border Group

LYNEBANK BEDS

Algae
Algal nodules, 1, 2
Aphralysia carbonaria Garwood, 3
A. sp., 5
Bevocastria conglobata Garwood, 3
Coelosporella wetheredii Wood, 3
Garwoodia gregaria (Nicholson), 2, 3
Girvanella amplifurcata Pia, 5
G. ducii Wethered, 2, 5
G. nicholsoni (Wethered), 3, 5
G. staminea Garwood, 3
G. wetheredii Chapman, 2, 3, 5
G. sp. nov., 5
Ortonella furcata Garwood, 2, 3, 4a, 5
O. kershopensis Garwood, 2, 3, 4a, 5
O. tenuissima Garwood, 4a

Annelida
Serpula advena Salter, 3
S. sp., 1, 2, 3, 5
Spirorbis sp., 4g

Brachiopoda
Antiquatonia teres (Muir-Wood), 1, 2, 3, 4e, 4g, 6
Athyris concentrica (von Buch), 3, 4c
'*Camarotoechia*' *sp.*, 2
Cleiothyridina sp., 2
Orbiculoidea nitida (Phillips), 3, 4g
Pustula interrupta Thomas, 3, 5
Schuchertella ambigua (Muir-Wood), 3, 4e
Smooth spiriferoids indet., 3, 4e, 4f [cf. *Composita.*]
Spirifer sp., 4e

Gastropoda
Euomphalus sp., 3
Naticopsis sp., 5
Turreted gastropods indet., 3

Bivalvia
Aviculopecten sp., 3, 4g
Edmondia cf. *laminata* (Phillips), 3
E. ?, 3
Leiopteria sp., 3, 4g
Modiolus cf. *latus* Portlock, 3, 4b, 4e, 4g
Myalina cf. *pernoides* (Portlock), 3
M. sp., 3, 4g, 5
Nuculopsis cf. *gibbosa* (Fleming), 3
Parallelodon sp., 3, 4g
Polidevcia attenuata (Fleming), 4b, 4e
Sanguinolites variabilis (McCoy), 4d, 4e, 4g
S. sp., 3, 4b, 4g
Schizodus cf. *pentlandicus* (Rhind), 3
S. sp., 3

Ostracoda
Beyrichiopsis cf. *carinata* Green, 3A, 3B
Carbonita [*Argilloecia*] *sp. nov.*, 3A, 3B
Cavellina attenuata (Jones and Kirkby), 3A, 3B
C. extuberata (Jones and Kirkby), 3A
Glyptopleura sp. nov., 3A
Knoxiella sp. nov. 1, 3A, 3B
Lichvinia sp. nov., 3B
Paraparchites sp., 3A, 3B
'*Primitia*' *sp. nov.*, 3A
Ostracods undetermined, 2, 3, 4a, 4c, 4d, 4g

Holothurioidea
Eocaudina cf. *scotica* Frizzell and Exline, 4e

BEWCASTLE BEDS

Algae

Aphralysia sp., 12
Bevocastria conglobata Garwood, 10, 11, 12
Garwoodia gregaria (Nicholson), 9a, 9e, 9f, 9g, 11, 12, 13, 15a, 15b
Girvanella ducii Wethered, 9b, f, g, 10, 11, 12, 13, 14a, b, 15a, b
G. nicholsoni (Wethered), 9c, d, 10, 11, 12
G. staminea Garwood, 14a
G. wetheredii Chapman, 9b, c, g, 10, 11, 12, 13
G. spp. nov., 9b, 10, 11, 13, 14b
Gymnocodium sp. nov., 9a, d
Koninckopora sp., 9d, 10
Ortonella furcata Garwood, 9a, c, g, 10, 11, 12, 13, 14b
O. kershopensis Garwood, 9a, 10, 11, 12, 13, 14b
O. tenuissima Garwood, 10, 11, 13
O. sp., 9f
Solenopora sp., 10

Annelida

Serpula sp., 9f, 12, 13
Spirorbis sp., 13

Brachiopoda

Antiquatonia teres (Muir-Wood), 7, 13
Composita aff. *ambigua* (J. Sowerby), 13
C. sp., 13
Lingula aff. *squamiformis* (Phillips), 13
Ovatia bioni (Muir-Wood), 13

Gastropoda

Donaldina sp., 13
Euphemites sp. nov., 13
Hypergonia sp., 13
Plagioglypta sp., 13

Bivalvia

Aviculopecten plicatus (J. Sowerby), 13
A. sp., 13
Edmondia cf. *laminata* (Phillips), 13
Leiopteria laminosa (Phillips), 13
Modiolus latus (Portlock), 13
M. sp., 9b, 10, 13
Myalina pernoides (Portlock), 9b, 13
Nuculopsis aff. *gibbosa* (Fleming), 13
Polidevcia attenuata (Fleming), 13
Sanguinolites plicatus (Portlock), 13
S. sp., 13
Schizodus sp., 13

Ostracoda

Cavellina sp., 13
Glyptopleura sp., 13
Knoxiella sp., 13
Paraparchites sp., 8, 13
Ostracods indet., 8, 9c, 9d, 13

Problematica

Draffania sp., 9a, 9b

MAIN ALGAL BEDS
(excluding unsectioned algal nodules)

Algae

Aphralysia sp., 19d, f, 20a, 25
Bevocastria conglobata Garwood, 16b, 17, 18, 19d, e, f, 20a, 23b, 25
Garwoodia gregaria (Nicholson), 16b, 19d, f, h, 20a, 21, 23b, 24, 25, 26, 27
Girvanella amplifurcata Pia, 16a, 17, 18, 19h, 23b, 24, 25, 27, 33
G. ducii Wethered, 16c, 17, 18, 19b, d, 21, 23b, 24, 25, 26, 27
G. nicholsoni (Wethered), 16c, 17, 18, 19g, 23b, 27
G. staminea Garwood, 25, 36
G. wetheredii Chapman, 18, 24, 25, 36
G. spp. nov., 16b, 17, 18, 25, 27
Gymnocodium sp., 19d, 20a
Koninckopora inflata (de Koninck), 17
K. tenuiramosa Wood, 17, 25
Ortonella furcata Garwood, 16a, b, c, 17, 18, 19d, f, g, h, 20a, 23b, 24, 25, 26, 36, 37
O. kershopensis Garwood, 16b, 17, 18, 19b, c, d, f, g, h, 23b, 24, 25, 26, 27, 36
O. tenuissima Garwood, 17, 18, 23b, 25, 36
O. sp., 19e
Solenopora garwoodi Hinde, 19a, 20b

Annelida

Serpula sp., 17, 25
Spirorbis sp., 25

Brachiopoda

Antiquatonia teres (Muir-Wood), 22, 25
'*Camarotoechia*' *sp.*, 22
Composita sp., 22
Lingula cf. *mytilloides* J. Sowerby, 23a, 25
Orbiculoidea nitida (Phillips), 23a, 25
Ovatia bioni (Muir-Wood), 23a, 25, 28
Schizophoria?, 25

Gastropoda
Plagioglypta sp., 23a, 25
Bellerophon sp., 25
Retispira [*Bucanopsis*] *sp. nov.*, 23a
Straparollus sp., s.l., 28
Turreted gastropods indet., 23a

Bivalvia
Aviculopecten cf. *plicatus* (J. Sowerby), 23a
A. cf. *subconoideus* (Etheridge jun.), 17, 25
A. sp., 28
Cardiomorpha sp., 23a
Edmondia sp., 23a
Leiopteria sp., 17, 28
Modiolus sp., 25
Myalina pernoides (Portlock), 28
Palaeoneilo sp., 17
Polidevcia attenuata (Fleming), 17, 23a, 25
Pteronites latus McCoy, 23a, 25, 28
Sanguinolites plicatus (Portlock), 23a
S. striatus Hind, 25
S. cf. *tricostatus* (Portlock), 23a
S. sp., 17, 22, 23a, 25, 28
Schizodus axiniformis (Portlock), 23a
S. pentlandicus (Rhind), 25
S. sp., 17, 23a, 25

Nautiloidea
Dolorthoceras sp., 25

Ostracoda
Cavellina cf. *longula* Cooper, 25
C. sp., 25
Glyptopleura sp. nov. (*costata* group), 25
Knoxiella sp. nov. 1, 25
Paraparchites cf. *pinguis* Green, 25
'*Primitia*' *sp. nov.*, 25
Ostracods undetermined, 17, 22, 23a, 25, 28

CAMBECK BEDS

Algae
Aphralysia sp., 33, 44
Garwoodia gregaria (Nicholson), 35a, **42, 43**
G. sp., 33, 34, 42
Girvanella amplifurcata Pia, 33, 35a, 42, 43
G. ducii Wethered, 34, 35a, b, 42, 43
G. nicholsoni (Wethered), 42, 43
G. staminea Garwood, 35a, 42
G. wetheredii Chapman, 33, 42, 43, 44
Koninckopora inflata (de Koninck), 35a, b
Ortonella furcata Garwood, 33, 34, 35a, b, 42, 43
O. kershopensis Garwood, 33, 35a, 42, 43
O. tenuissima Garwood, 33
Algal nodules (unsectioned), 30, 31, 38b, 42

Bryozoa
Fenestella sp., 32, 40, 42
Trepostomatous bryozoan, 32

Annelida
Serpula sp., 42
Spirorbis sp., 36, 42

Brachiopoda
Antiquatonia teres (Muir-Wood), 30, 32, 33, 34, 36, 38a, 39, 40, 42
'*Camarotoechia*' *fawcettensis* Garwood, 34, 36
C. sp., 32, 33, 36
Cleiothyridina glabristria (Phillips), 30G, 31G
Eumetria sp. nov., 38a
Lingula squamiformis (Phillips), 33a
L. sp. 32, 38a, 40
Orbiculoidea nitida (Phillips), 32, 33, 38a, 39
Ovatia bioni (Muir-Wood), 30, 31, 32, 33, 34, 36, 40
Phricodothyris sp., 40
Punctospirifer scabricosta North, 34, 41, 42
Pustula pyxidiformis (de Koninck), 42
P. sp., 44
Schuchertella ambigua (Muir-Wood), 33, 35c, 36, 37, 38a, 42, 44
Smooth spiriferoids indet., 30, 31, 32
Spirifer sp. (*striatus* group), 34, 36, 38a
Spiriferellina sp., 40
Syringothyris exoleta North, 32, 33, 37, 38b, 42
S. sp. 34, 38a

Gastropoda
Retispira [*Bucanopsis*] *sp.*, 34
Turreted gastropods indet., 38a, b, 42
Plagioglypta sp., 38a

Bivalvia
Acanthopecten sp. nov., 34
Aviculopecten plicatus (J. Sowerby), 34, 42
A. subconoideus Etheridge jun., 32
A. sp., 30, 32, 33, 34, 38a, b, 39, 40
Cardiomorpha sp., 34
Leiopteria divisa Hind (*non* McCoy), 40
Myalina pernoides (Portlock), 32, 34, 38b
M. sp., 33, 38a, b

Polidevcia cf. *attenuata* (Fleming), 34, 38a
Pteronites latus McCoy, 34, 38a, 40
Sanguinolites cf. *clavatus* (Etheridge jun.), 32
S. cf. *striatus* Hind, 32
S. cf. *tricostatus* (Portlock), 42
S. aff. *variabilis* McCoy, 34
S. sp., 34, 38a, b, 39
Schizodus sp., 32, 33, 34, 36, 38a, 39
Streblochondria sp., 40

Ostracoda
Bairdia cf. *kinderhookensis* Morey, 36
B. sp., 36
Cavellina sp., 36
Glyptopleura sp., 36, 42
Hollinella cf. *radiata* (Jones and Kirkby), 34, 36, 38a
Knoxiella sp. nov. 2, 36
Monoceratina sp. [*Triceratina*-like], 36
Paracavellina sp., 36
Paraparchites cf. *pinguis* Green, 36
P. sp., 34, 36, 38a
Punctomosea sp., 36
Ostracods undetermined, 32, 34, 36, 38a, b, 40, 42

Echinoidea
Archaeocidaris sp., 36, 40

Holothurioidea
Eocaudina scotica Frizzell and Exline, 38a

MIDDLE BORDER GROUP

Algae
Aphralysia sp., 55
Girvanella ducii Wethered, 54a, 56c
G. staminea Garwood, 52b, 54a, 56b, c
G. wetheredii Chapman, 54a, 56c
G. sp. nov., 54a
Koninckopora inflata (de Koninck), 56c
Ortonella furcata Garwood, 56b
Algal nodules, 46a

Anthozoa
Lithostrotion sp. with cerioid tendencies, 48

Bryozoa
Dyscritella nana Lee, 53 [holotype]
Fenestella cf. *matheri* Condra and Elias, 48
F. occulata McCoy, 55
F. sp., 45c, 53, 55
Trepostomatous bryozoa indet., 54b, 55

Annelida
Spirorbis sp., 45d, f, 47, 55

Brachiopoda
Antiquatonia teres (Muir-Wood), 48, 51b, 55
'*Camarotoechia*' *sp.*, 55, 56a
Composita ambigua (J. Sowerby), 49b, 51a, 54a, 55
C. sp., 45e, 46a, 56b
Chonetes? s.l., 48
Echinoconchus punctatus (J. Sowerby), 49b, 50, 51c
Lingula cf. *mytilloides* J. Sowerby, 48, 55
L. cf. *squamiformis* Phillips, 45b, d, 46a, 53
Linoproductus sp. [*corrugatus* group], 55
Ovatia bioni (Muir-Wood), 48, 49a, 50, 55, 56a
O. sp., 47, 48, 50, 54a
Punctospirifer scabricosta North, 53, 54b, 54c, 55
Pustula cf. *pyxidiformis* (de Koninck), 51b, 56b
Rugosochonetes cumbriensis (Muir-Wood), 49a, 51b, 56a
Schuchertella ambigua (Muir-Wood), 49a, 51b, 55, 56b
Smooth Spiriferoids indet., 48, 49a, 55
Syringothyris cf. *exoleta* North, 55

Gastropoda
Bellerophon sp., 45d
Naticopsis sp., 47
Retispira [*Bucanopsis*] *sp.*, 46a, 47, 48, 55
Plagioglypta sp., 48, 52a

Bivalvia
Aviculopecten plicatus (J. de C. Sowerby), 47
A. sp., 45d, 47, 48, 49b, 52a, 55, 56a
Edmondia sulcata (Phillips), 54a
Leiopteria divisa Hind (*non* McCoy), 48, 52a, 55
L. laminosa (Phillips), 58
L. sp., 45e, f
Modiolus latus Portlock, 46b
M. sp., 45b, d, 46a, 47
Myalina peralata de Koninck, 45b
M. cf. *pernoides* (Portlock), 48, 52a, 55
M. verneuili (McCoy), 46a, 47, 48
Naiadites cf. *crassus* (Fleming), 55
Palaeoneilo cf. *laevirostris* (Portlock), 48
Parallelodon sp., 46a, 48, 52a

Polidevcia attenuata (Fleming), 45a, e, 46a, 4,7 48, 52a, 55
Pteronites angustatus McCoy, 48, 55
Sanguinolites cf. *clavatus* (Etheridge jun.), 45a, 47, 55
S. cf. *plicatus* (Portlock), 48
S. cf. *tricostatus* (Portlock), 48
Schizodus sp., 46a, 48
Streblochondria sp., 50, 55

Nautiloidea
Catastroboceras sp., 55
Orthocone nautiloids, 47, 53, 55

Ostracoda
Ostracods undetermined, 45a, b, c, d, f, 46a, b, 48, 49a, 51b, 52a, 55, 56a

Echinoidea
Archaeocidaris sp., 56a

Holothurioidea
Eocaudina sp., 55

Pisces
Cochliodont tooth, 55
Fish debris, 46a

UPPER BORDER GROUP

Algae
Girvanella staminea Garwood, 62f

Foraminifera, 68f

Anthozoa
Caninia sp., 85b
Caniniid indet., 61a, 67, 68b, 77c
Carcinophyllum sp., 76b
Chaetetes depressus (Fleming), 62e, 67
C. septosus (Fleming), 66
Diphyphyllum sp., 75, 81
Lithostrotion martini Milne Edwards and Haime, 59, 61a, 62c, 63b, 67, 68a, f, 70b, f, 72a, 74, 75, 76b, 77b, c, 87b, 90
L. pauciradiale McCoy, 70d
L. portlocki Bronn, 62b, 68a, 70f, 72a, 74, 75, 77b, c
L. aff. *portlocki*, crenulate corallite margins, 70f, 72a
L. sp., 60a, 61a, 63a, b, 65, 70d, 75, 80a, 85a, b
Syringopora geniculata Phillips, 70f
S. sp., 60a, 62e, 68b, 72b, 77c
Zaphrentid coral indet., 77b

Scyphozoa
Paraconularia sp., 72b, 75, 77i, 85b

Annelida
Spirorbis sp., 77h, 82, 87a, b, 90
Scolecodonts, 77, 90

Bryozoa
Dyscritella nana Lee, 70a, c, 79, 82b, 86
D. sp., 75
D. ?, 58, 71a
Fenestella frutex McCoy, 59, 62d, 63a, b, 65, 67, 69, 70c, f, 72a, 77b, c, i, 81, 85a, 87a, b, 90
F. cf. *matheri* Condra and Elias, 77d
F. cf. *oblongata* Koenig, 72a
F. cf. *occulata* McCoy, 75
F. sp., 60a, 61a, 63a, b, d, f, 64, 70e, 72b, 75, 77a, b, c, e, g, 78c, 80a, 82, 84a, 85b, 87a, b, 88
Hemitrypa hibernica McCoy, 63f
Penniretepora sp., 63a, 85a
Stenodiscus sp., 70f, 75
Trepostomatous bryozoa indet., 59, 62d, 63a, b, c, d, 64, 67, 75, 77b, c, g, i, j, 84a, 87a, 90

Brachiopoda
Buxtonia sp. nov., 59, 62a, d, 63a, b, 64, 67, 71a, 75, 77a, b, c, f, g, h, i, j, 78b, 80a, b, 81, 82a, b, 84a, b, 85a, b, 86, 87b
B. sp., 57, 63b, 65, 77d, 87a
'*Camarotoechia*' *sp.*, 61a, 62b, 63a, b, 64, 65, 70c, f, 71a, 75, 77b, c, d, e, f, g, h, i, j, 84b, 85a, b, c, 86, 87b, 88, 89, 90
Chonetes sp. s.l. [small, tumid, smooth.] 68d
Cleiothyridina sp., 59, 61a, b, 73, 78a
Composita cf. *ambigua* (J. Sowerby), 63b, 77b, c, g, 87b, 88
C. sp., 77f, i, 85a
Craniid indet., 77h
Dielasma sp., 68b, 80a, 87a
Echnioconchus cf. *elegans* (McCoy), 59, 61a, 63a, 73, 75, 77c, 81, 87a
E. punctatus (J. Sowerby), 63b, 68b, 70f, 75, 77a, b, c, 85b, 87b
E. sp., 63f, 70f, 72b, 73, 75
Fluctuaria cf. *undata* (Defrance), 75
cf. *Georgethyris elliptica* (Phillips), 77c
cf. *Gigantoproductus maximus* (McCoy), 68f
Lingula cf. *mytilloides* J. Sowerby, 77h, i
L. aff. *squamiformis* Phillips, 71b, 82, 86, 88, 90

L. sp., 77b
Linoproductus corrugatus (McCoy), 69
L. sp., 57, 62a, d, 63a, b, c, 75, 76b, c, 82a, b, 84b, 85a, c, 87a, 90
Martinia sp., 63a, 75, 77c
cf. *Martinothyris lineata* (J. Sowerby), 76b
Pleuropugnoides [*Camarotoechia*] cf. *pleurodon* (Phillips), 62d, 77a, b, c
Productus garwoodi Muir-Wood, 62a, d, 63a, b, 65, 67, 75, 77b, g, i, 80a, b, 84a, b, 86
P. cf. *garwoodi*, 57, 61a, 64, 70c, f, 75, 77b, f, 85c, 89
P. aff. *redesdalensis* Muir-Wood, 75
P.?, 60a, 77a, b, c, f
Punctospirifer scabricosta North, 63a, b, 67, 69, 70e f, 75, 76a, 77a, b, c, d, g, 79, 80a, 82a, 83, 84a, b, 86, 87a, 88, 90
P. sp., 59, 72b
Rugosochonetes cf. *hardrensis* (Phillips), 75
R. sp., 87a
Semiplanus sp. nov., 59, 60a, 61a, 62c, e, 63a, b, 65, 68c, 70b, c, f, 72a, b, 74, 75, 76b, 77b, c, 80a, b, 87b, 90
S.?, 68a, b, 76c
Smooth spiriferids indet., 61a, 62d, 63a, b, d, f, 64, 73, 75, 77a, b, c, 81, 90
Spirifer cf. *trigonalis* (Martin), 63b, 77a, b, c, 85b
S. sp., 61a, 62e, 64, 73, 75, 77a, c, g, 81, 85a, 87b
Spiriferellina cf. *octoplicata*, 75
Stenoscisma isorhyncha (McCoy), 67, 70f, 72a, 76b, 80a, 81, 90
cf. *S. isorhyncha*, 60a, 63e, 70f, 71b, 72b, 75
Trigonoglossa scotica (Davidson), 72b

Gastropoda
Araeonema cf. *conica* (de Koninck), 75
Baylea cf. *concentrica* (Phillips), 70f
Bellerophon cf. *costatus*, 87a
B. latisulcatus Weir, 72b
B. sp., 70c, f, 72c, 75, 77a, b, c, f, i, 78b, 86, 87a, 89
Donaldina sp., 75, 77j
Euphemites urii (Fleming), 35
E. sp., 63a, 72b, 77b, 80a, 86
Hypergonia cf. *acuticarinata* Longstaff, 75
H. quinquecarinata (de Koninck), 70f
H. sp., 75, 77b, e, i, 80a, 82, 90
Naticopsis sp., 70f, 75, 77a, b, c, e, f, 89, 90
Platyconcha sp., 75
Retispira [*Bucanopsis*] cf. *decussata* (Fleming), 75
R. striata (Fleming), 77e
R. aff. *imbricata* (Weir), 75
R. sp., 75, 77b, 80a
Soleniscus sp., 80b, 82
Straparollus (*Euomphalus*) *calyx* (Phillips), 77b
S. (*E.*) *pentangulatus* (J. Sowerby), 70f
S. sp. s.l., 70f, 75, 77b, c, i, 78b, 85c, 87a, b
Turreted gastropods indet., 63a, 70f, 73, 75, 77b, e, 82, 88, 90
Gastropods indet., 77b, c, j, 78b, 80a, 90

Bivalvia
Acanthopecten sp., 77b, 80a
Aviculopecten eskdalensis Hind, 76c, 85c, 88
A. interstitialis (Phillips), 77b, c, d, f, 87b
A. cf. *plicatus* (J. de C. Sowerby), 57, 63b, 75, 82a, 83, 85a, 87a
A. cf. *subconoideus* Etheridge jun., 60a, 75, 87b, 88
A. sp., 64, 65, 72a, 75, 76b, 77a, b, e, h, 78c, 80a, b, 82a, 84a, c, 87a, b, 88, 89, 90
Cardiomorpha?, 63a
Curvirimula?, 77b
Cypricardella rectangularis (McCoy), 63a
Leiopteria divisa (McCoy), 63b, 70f, 75, 76a, 77a, b, e, 80a, 82a, 86, 87b, 90
L. thompsoni (Portlock), 75
L. sp., 77i, j, 78b, 82a, b, 83, 84b, 85a, 87a, 89
Edmondia laminata (Phillips), 75
E. cf. *sulcata* (Phillips), 63a, 80a, 82a, 84b, 85a
E. sp., 73, 75, 77b, j, 82a, 88
Modiolus cf. *latus* Portlock, 78b, 83, 87b
M. sp., 57, 63a, 71b, 75, 77c, e, f, j, 78b, 85a, 87b, 88, 90
Myalina cf. *pernoides* (Portlock), 60b, 69, 71b, 75, 76a, b, 77b, c, d, e, i, 78b, 82a, 87b, 88, 89
M. sublamellosa (Etheridge jun.), 76c
M. sp., 77b, c, f, 78a, 82a, 83, 85a, 87b, 88
Mytilomorpha cf. *rhombea* (Phillips), 75
Naiadites crassus (Fleming), 57, 61b, 75, 77b, d, g, h, 78b, c, 82a, 86, 87a, b, 88, 89, 90
N. obesus (Etheridge jun.), 77c
N. sp., 77d
Nothamusium transversum Hind, 63b
N. radiatum Hind, 77j
Nuculopsis gibbosa (Fleming), 57, 75, 90
Palaeolima cf. *simplex* (Phillips), 63a
Palaeoneilo laevirostris (Portlock), 75
P. cf. *luciniformis* (Phillips), 80a
P. sp., 57, 71b, 72b, 75
Parallelodon cf. *reticulatus* (McCoy), 75
Polidevcia attenuata (Fleming), 60b, 61a, 70f, 72b, 75, 77b, d, e, g, i, 78b, 82a, 83, 86, 87a, b, 89, 90
Promytilus cf. *oblongus* (McCoy), 60a, 75, 77b
Prothyris oblonga Wilson, 75
P. sp., 75

Pterinopectinella rigida (McCoy), 76c
Pteronites angustatus McCoy, 63b, 76b, 82a, 83, 84b, 87a, 90
P. latus McCoy, 75, 78b
P. sp., 77i, 82a
Sanguinolites cf. *clavatus* (Etheridge jun.), 75, 80a, 86, 87a, 88, 90
S. cf. *tricostatus* (Portlock), 76b, 77b
S. sp., 69, 71b, 75, 77b, c, g, i, 82, 86, 87b, 89
Schizodus axiniformis (Phillips), 77b
S. cf. *pentlandicus* (Rhind), 57, 87a
S. sp., 57, 75, 77b, c, h, i, 78b, 80a, 86, 87a, b, 88, 89
Streblochondria sp., 63b, 67, 77d, 87b
Sulcatopinna sp., 75

Nautiloidea
Catastroboceras cf. *sulcatum* (J. de C. Sowerby), 75
Poterioceras sp., 70f
Coiled nautiloid indet., 77b, 90
Orthocone nautiloids, 64, 73, 76b, 77b, c, e, 82a, 85a, 88, 89

Ostracoda
Acratia fabaeformis Green, 70f
Bairdia brevis, 70f
B. submucronata Jones and Kirkby, 70f
B. sp., 70f, 77h
Beyrichiopsis fimbriata Jones and Kirkby, 90
B. subdentata Jones and Kirkby, 90
B. sp., 90
Carbonita fabulina (Jones and Kirkby), 90
C. [*Argilloecia*] *sp.*, 90
Cavellina longula Cooper, 70f, 90
C. subpulchella Coryell, 90
C. cf. *valida* (Jones and Kirkby), 70f
C. sp., 90
Glyptopleura plicata (Jones and Kirkby), 90
G. [*Chesterella*] *sp. nov.*, 70f
G. sp. nov., 3, 70f
Hollinella sp., 63a
Lichvinia? *spiralis* (Jones and Kirkby), 90
Kloedenellitina sp. nov., 90
Knoxiella sp. nov., 90
Microcoelonella sp., 70f
Monceratina antiqua (Jones and Kirkby), 90
Oliganiscus sp., 70f
Paraparchites inornatus (McCoy), 70f, 90
P. sp., 77e, f, 90
Pseudobythocypris cuneola (Jones and Kirkby), 70f, 90
Sulcella sp. nov., 90

Trilobitomorpha
Weberides sp., 70f, 72a
Trilobite fragments indet., 70e

Echinoidea
Archaeocidaris sp., 62d, 70e, 75, 77b, c

Holothurioidea
Eocaudina cf. *scotica* Frizzell and Exline, 63a

Pisces
Cochliodont tooth, 77b, 81
Fish debris indet., 75, 90

LIDDESDALE GROUP

In the following list, fossils from the Penton Linns section (loc. 99) and also those from localities 91 a–c and 100–102 were determined by Dr. R. B. Wilson and the collections from these localities are housed in the Institute's Edinburgh Office. A fuller list of fossils from the Liddel Water is given by Dr. Wilson (*in* Lumsden and others 1967).

Algae
Algal nodules, 92e, 99k, 104

Foraminifera
Saccamminopsis fusulinaformis (McCoy), 99b

Anthozoa
Aulophyllum fungites (Fleming), 92e
A. fungites pachyendothecum Thomson, 99k
Caninia benburbensis Lewis, 94b
C. sp., 92c, 93, 97a
Carcinophyllum vaughani Salée, 97a
C. sp. nov. aff. *vesiculare* Thomson, 104
Clisiophyllum sp., 92d, 99k
Dibunophyllum bipartitum bipartitum (McCoy), 99k
D. cf. *bourtonense* Garwood and Goodyear, 99j
D.?, 104
Diphyphyllum cf. *lateseptatum* McCoy, 99k, 100a
Fasciculophyllum sp., 94d
Lithostrotion junceum (Fleming), 92c, 95a, 96, 99b, k, 100a, b, 103a, b, 104

L. maccoyanum Milne Edwards and Haime, 103b, 105
L. martini Milne Edwards and Haime, 91e, 98b
L. pauciradiale (McCoy), 92c, d, 94b, 97a, 99e, i, 101a, b, 102a
L. sp., 94d
Lonsdaleia duplicata melmerbiensis Smith, 98b
L. floriformis floriformis (Martin), 104
Microcyathus cf. *cyclostomus* (Phillips), 99e
Rotiphyllum sp., 97a
Syringopora sp., 104
Zaphrentites derbiensis (Lewis), 95b
Zaphrentid corals indet., 92b, 94a

Scyphozoa
Campylites sp., 97b
Conularia sp., s.l., 99h

Bryozoa
Fenestella matheri Condra and Elias, 97a
F. occulata McCoy, 97b
F. sp., 91a, e, 92b, 94d, 97a, b, 99a, b, e, 100b
Penniretepora sp., 92b, 94d, 99a
Trepostomatous bryozoa, 92b, 97b, 99c, k

Brachiopoda
Antiquatonia sp., 91e, 92b, 93, 99a
Avonia youngiana (Davidson), 99a, b, 100a
Brachythyris ovalis (Phillips), 91b, 99k, 102a
Buxtonia sp. nov. [Redesdale Ironstone Shale form], 94a, 97b
Cleiothyridina fimbriata (Phillips), 94c, 97b, 99a
Composita cf. *ambigua* (J. Sowerby), 91a, 92a, c, 94b, c, 100c
Crurithyris sp., 99a, 100b
Echinoconchus cf. *elegans* (McCoy), 100a
E. punctatus (J. Sowerby), 94a
E. sp., 99f
Eomarginifera cf. *lobata*, 100a, b
E. praecursor, 99a
E. setosa (Phillips), 99a, b, e
E. sp., 94d
Fluctuaria sp., 92a, b, 93, 94d, 95
Fusella cf. *triangularis* (J. de C. Sowerby), 94d
Gigantoproductus giganteus (J. Sowerby) group, 99b, i, k, 100b
G. maximus (McCoy) group, 91c, f, 96, 98a
G. aff. *sarytscheffi* (Paeckelmann), 91b
G. cf. *striatosulcatus* (Sarycheva), 103a, b
G. sp. [latissimoid], 99e, i, k, 102b, 103a
G. sp., 94c, d, 97a
Lingula cf. *mytilloides* J. Sowerby, 94d, 99e
L. cf. *squamiformis* Phillips, 99e, f
L. sp., 97b, 100b
Linoproductus sp., 91b, 99d
Martinia sp., 94d
Martinothyris cf. *lineata* (J. Sowerby), 99b
Orbiculoidea cf. *nitida* (Phillips), 91b, 99e
Orthotetids indet., 91c, 99e, 100c, 101a
Phricodothyris sp., 91c
Pleuropugnoides cf. *pleurodon* (Phillips), 102a
P. sp., 99c, h, 100c
Plicochonetes sp., 92d, 99f, k
Productus concinnus J. Sowerby, 99a
P. cf. *productus* (Martin), 99d
P. redesdalensis Muir-Wood, 97b, 102a
P. sp., 91b, c, 92a, 93, 97b, 102a
Pugilis pugilis (Phillips), 91d, 97a, 99k
P. scoticus (J. Sowerby), 99d, h, 100b
Pugnax?, 91b, c, 100a
Punctospirifer redesdalensis North, 91a, c, 92a, b, 97b
Quasiavonia cf. *aculeata* (J. Sowerby), 100a
Rhipidomella michelini (Léveillé), 99h, i
Rhynchotetra?, 100b
Rugosochonetes cf. *hardrensis* (Phillips), 91e, 92a, b, 94d, 99c, 102b
R. aff. *laguessianus* (de Koninck), 91d, 99e, h, 101a
R. speciosus (Cope), 99a
Schellwienella sp., 99a, d
Schizophoria?, 99a, 102a
Smooth spiriferoid indet., 92e
Spirifer bisulcatus (J. de C. Sowerby) group, 100b
S. striatus (Martin) group, 99a
S. trigonalis (Martin) group, 94d, 99b
S. sp., 94c, 99h, 100a
Spiriferellina cf. *octoplicata* (J. de C. Sowerby), 94a, 99a
S. cf. *perplicata* North, 91a
Tornquistia polita (McCoy), 99b, 100a
T. sp., 92b
Tylothyris subconica (Martin), 99e

Gastropoda
Amphiscapha catilla (Martin), 99k
Bellerophon cf. *costatus* J. de C. Sowerby, 97b
B. cf. *randerstonensis* Weir, 99d
B. sp., 104
Donaldina sp., 99a
Euphemites cf. *pentonensis* (Weir), 99c, e, 100b
E. sp., 94d, 97b, 99f
Glabrocingulum beggi E. G. Thomas, 99e
Latischisma globosa E. G. Thomas, 101b
Microptychis sp., 99j
Mourlonia griffithi (McCoy), 99h
Naticopsis variata (Phillips), 99d, e, k,
N. sp., 94d, 97a, 99e, i
Pseudozygopleura cf. *rugifera* (Phillips), 99e, j

Retispira [*Bucanopsis*] *decussata* (Fleming), 91b
R. striata (Fleming), 99e
R. sp., 91b, 92b, 97b, 99d
Straparollus sp., 94a
Tropidodiscus gratiosus (de Koninck), 97b

Bivalvia
Actinopteria persulcata (McCoy), 94d
Aviculopecten tabulatus McCoy, 91a
A. sp., 91b, e, 92b, 97a, b, 99a, e
Aviculopinna cf. *mutica* (McCoy), 91b, 99a
Conocardium cf. *alaeforme* (J. de C. Sowerby), 101b
C. sp., 99c
Cypricardella rectangularis (McCoy), 94a, c, 99e, h
Edmondia pentonensis Hind, 99e
E. sulcata (Phillips), 91b, c, 99c
E. cf. *unioniformis* (Phillips), 99i
E. sp., 96, 99k
Euchondria sp. nov., 91b, 97b
Leiopteria cf. *thompsoni* (Portlock), 91b
L. sp., 91a, 99h
Limipecten dissimilis (Fleming), 99k
L. sp., 93
Lithophaga lingualis (Phillips), 99a, k
Modiolus sp., 99d
Myalina sp., 99a, h
Mytilomorpha sp., 99e
Naiadites sp., 91b
'*Nucula*' *oblonga* Hind (*non* McCoy), 99c, e
Nuculopsis gibbosa (Fleming), 97b, 99e, h
Palaeolima cf. *simplex* (Phillips), 94d
Palaeoneilo laevirostris (Portlock), 92b, 95
P. luciniformis (Phillips), 99e, h
P. sp., 94a, c
Parallelodon sp., 99d
Pernopecten sowerbii (McCoy), 92b, 94d, 99a 100b
P. sp., 99c, d, g
Polidevcia attenuata (Fleming), 91b, 92b, 99e, h
P. brevirostris (Phillips), 91b, 99e
P. sp., 99d
Posidonia becheri Bronn, 99e, 101a
Prothyris oblonga Wilson, 97b
Pterinopectinella rigida (McCoy), 91d
Pt. sp., 99e
Pteronites angustatus McCoy, 97b
Sanguinolites striatus Hind, 91b
S. variabilis McCoy, 94d, 99e, 102a
Schizodus cf. *axiniformis* (Portlock), 91b
S. aff. *trigonalis* (de Koninck), 91b
S. sp., 91b, 99e
Sedgwickia attenuata?, McCoy, 91b
S. ovata Hind, 91b
Solemya primaeva Phillips, 99k
Solenomorpha sp., 91b
Streblochondria anisota (Phillips), 99a, 100b
S. sp., 94d
Streblopteria concentricolineatum Hind, 102a
Sulcatopinna flabelliformis (Martin), 96, 99c, 100b
Wilkingia elliptica (Phillips), 99c, 100b

Nautiloidea
Epistroboceras sp., 92c
Coiled nautiloids indet., 92b, 99e
Orthocone nautiloids indet., 97b, 99e, h

Ammonoidea
Beyrichoceratoides truncatus? (Phillips), 99e
Goniatite fragments indet., 99e

Ostracoda
Ostracods undetermined, 92d, e, 94c, d, 97b
Weberides sp. [mucronate pygidium], 99a

Trilobitomorpha
Trilobite fragments, 94c, d, 97a, 99b, c, d, h, 100a

Echinoidea
Echinoid spine, 100a

SELECTED LOCALITIES OF FOSSILS

National Grid references are given in square brackets, and the registered numbers of the specimens in the collections of the Institute are quoted.

LOWER BORDER GROUP

LYNEBANK BEDS

1. Routledge Burn [5200 8338], 1480 yd S. 2° W. of English Kershope; YAF 625–9.
2. River Black Lyne, [5411 7821 to 5438 7850], from near Holmehead to N.W. of Hole of Lyne (see Appendix I), YAF 969, 976; YFF 2623–704.

3. Ellery Sike [5439 7584 to 5453 7575], at 310° from Nixonstown to junction with River White Lyne (see Appendix I), YEF 322–35; YFF 1042–93. Ostracod collections: 3A, 5 ft above Ellery Sike Limestone. 3B, at junction with White Lyne.
4. River White Lyne: (*a*) [5457 7567], 225 yd at 315° from Nixonstown; YFF 1017–41. (*b*) [5453 7575], 310 yd at 320° from Nixonstown; YEF 446–54. (*c*) [5435 7706], 100 yd W. of Murrayholme; RN 4348–56. (*d*) [5464 7695], 150 yd at 106° from Bankhead; RN 4357–65. (*e*) [5458 7666], 275 yd at 101° from Bankhead; RN 4366–80. (*f*) [5448 7737], 220 yd at 15° from Crook; RN 4383–9. (*g*) [5512 7788 to 5527 7794], 1050 yd at 46° from Crook and 200 yd upstream; RN 4390–452.
5. Bothrigg Burn [5482 7598 to 5457 7592], 230 yd S. of Rawney to confluence with River White Lyne; YEF 671–85.
6. Kirk Beck [5495 7448], 360 yd at 297° from Bogside; YEF 460.

BEWCASTLE BEDS

7. Keld Sike [5265 8476], 30 yd upstream from road bridge; YAF 622.
8. Fairies Sike [5297 8516], 530 yd 47° from English Kershope and up to 100 yd downstream; YFF 2793–9.
9. River Black Lyne: (*a*) [5426 7896], 850 yd N.N.E. of Holmehead; YAF 972–5. (*b*) [5409 7820 to 5418 7820], 70 to 180 yd E. of Holmehead; YAF 960–2. (*c*) [5405 7820], 30 yd E. of Holmehead; YAF 957–9. (*d*) [5392 7815], 90 yd S.W. of Holmehead; YAF 955–6. (*e*) [5390 7814], 110 yd S.W. of Holmehead; YAF 950–3. (*f*) [5349 7774], 240 yd upstream from Blackpool Gate Bridge; YAF 949. (*g*) [5426 7993], 1700 yd at 188° from Black Lyne House; YAF 940.
10. Bailey Water, [5162 8008], 240 yd at 114° from Grahams Onset; YAF 822–4.
11. Crubinshill Sike [5100 8027 to 5064 8028], in section between 300 yd E.S.E. to 50 yd S.W. of Crubinshill Farm; YFF 1699–1700, 1721–38.
12. Crook Burn [5023 7844 to 5050 7847], from 550 yd at 253° to 200 yd at 223° from Crookburn Farm (see Appendix I); YFF 1743–66.
13. Ashy Cleugh [5647 7698 to 5781 7670], section from road bridge upstream for 1400 yd (see Appendix I); RS 4271–506.
14. Green's Burn: (*a*) [5796 7453], 275 yd at 125° from Rigghead Barn; YEF 535–6. (*b*) [5782 7460], 100 yd at 120° from Rigghead Barn; YEF 533–4.
15. (*a*) Stream [5774 7515], 140 yd at 82° from Low Grains Farm; YEF 531. (*b*) stream [5863 7468], 800 yd at 197° from High Grains Farm; YEF 619–20.

MAIN ALGAL BEDS

16. Kirk Burn: (*a*) [5036 7111], 230 yd at 169° from Stapleton church; YEF 501–2. (*b*) [5040 7108], 25 yd W. of a point 240 yd at 165° from Stapleton church; YEF 508. (*c*) [5039 7108], at footbridge, 240 yd at 165° from Stapleton church; YEF 503–4.
17. Crook Burn [see Appendix I]; YFF 1782–1839.
18. Crubinshill Sike [5100 8027 to 5064 8028], in section between 300 yd E.S.E. and 50 yd S.W. of Crubinshill Farm; YFF 1683–98 1701–19.
19. Cuddy's Burn: (*a*) [5210 8180] 1150 yd upstream from Cuddy's Hall Bridge; YAF 935. (*b*) [5202 8142] 740 yd upstream from Cuddy's Hall Bridge; YAF 896. (*c*) [5202 8136], 690 yd upstream from Cuddy's Hall Bridge; YAF 895. (*d*) [5198 8114], 80 yd E. of Cuddy's Hall; YAF 889–91. (*e*) 5 yd E. of previous locality; YAF 892. (*f*) [5202 8119], 505 yd upstream from Cuddy's Hall Bridge; YAF 893. (*g*) 8 yd downstream from 19d; YAF 885–8. (*h*) [5199 8106], 365 yd upstream from Cuddy's Hall Bridge; YAF 939.
20. Hollin Cleugh: (*a*) [5274 8042], 615 yd upstream from road bridge; YAF 900, 932–3. (*b*) [5269 8045], 555 yd upstream from road bridge; YAF 899.

21. River Black Lyne [5422 8042], 1180 yd at 193° from Black Lyne House; YAF 947–8.
22. The Beck [5552 8228], 1430 yd at 12° from Kettle Hall; RN 4291–311.
23. River White Lyne (see Appendix I), (*a*) [5120 7297], *Orbiculoidea* Shale; YPF 667–705. (*b*) [5119 7298], 7 ft below MA 12; YPF 706–7.
24. Whitberry Burn (see Appendix I). [5227 7403], 160 yd at 163° from Hill End Farm; YFF 336–9.
25. Birky Cleugh (see Appendix I) [5937 7539 to 5885 7540]; YFF 2078–200; GSM 67827–61.
26. Quarry [5648 7224], 860 yd at 96½° from Wintershields Farm; YEF 615–6.
27. White Beck (see Appendix I); YEF 606–8.
28. Muckle Hare Grain [5770 8048], 2500 yd N.E. of the Flatt and up to 250 yd S.W.; RS 559–98.

CAMBECK BEDS

29. White Beck (see Appendix I); YEF 609–12.
30. Kershope Burn [4759 8294 to 4783 8299], from 50 to 300 yd upstream from railway bridge; YFF 1960–2000.
31. Station Quarry [4750 8280], Kershopefoot.
32. Crook Burn (see Appendix I), YFF 1840–1915; YAF 977–80.
33. Whitberry Burn (see Appendix I), YEF 340–54.
34. River White Lyne (see Appendix I), YPF 709–10.
35. Show Burn: (*a*) [5268 7215], 90 to 110 yd S.E. of Low Floweryhirst Farm; YEF 578–9. (*b*) [5316 7199], 630 yd at 14° from Allergarth Farm; YEF 596–7. (*c*) [5383 7195], 1295 yd at 113° from High Floweryhirst Farm; YEF 595.
36. Birky Cleugh, at ford [5932 7539]; YFF 2201–25.
37. Whams Sike, [5799 7863], 2850 yd at 318½° from Bull Cleugh Gate; YEF 872.
38. Muckle Hare Grain. (*a*) [5824 8032]; RS 5735–833. (*b*) [5833 8034]; RS 5963–88.
39. Gate Grain [5831 8110] 135 yd at 6° from confluence of Gate Grain and Rough Grain; RS 6047–65.
40. Rough Grain [5878 8107], 550 yd at 80½° from confluence of Gate Grain and Rough Grain; RS 6092–134.
41. Priorlancy Borehole (see Appendix 2); YAF 2425–513.
42. Cam Beck (see Appendix I); YEF 585–94.
43. Hillside [6002 7340], 210 yd at 325° from Hen Hill; YEF 539–40.
44. Butter Burn [6085 7424], 40 yd W. of a point 485 yd at 317° from Butterburn Hill; YEF 491–3.

MIDDLE BORDER GROUP

45. Riding Grain: (*a*) [5577 8703 and 5578 8705], section ii, 1060 ft at 88° from confluence with Kershope Burn, and tributary 1040 ft at 91½° from same point; YPF 3376–402. (*b*) [5590 8686], section iii, south bank tributary, 1580 ft at 113° from confluence of Riding Grain and Kershope Burn; YPF 3438–54. (*c*) [5605 8674], section iv, south bank tributary, 2200 ft at 116° from confluence with Kershope Burn; YEF 3458–63. (*d*) [5581 8706 to 5597 8708], section v, 1190 ft at 88°, 1480 to 1740 ft at 85° from confluence with Kershope Burn; YPF 3420–35, 3468–85. (*e*) [5604 8713 to 5604 8714], section vi, 1950 ft at 81° to 2000 ft at 80° from confluence with Kershope Burn; YEF 3486–95. (*f*) [5604 8701 and 5603 8699], Coal Grains, 1960 ft at 93°, also 1920 ft at 95°, from confluence of Riding Grain and Kershope Burn; YEF 3499–524.
46. River Black Lyne (see Appendix I): (*a*) [4984 7514], 277 to 280 yd S. of Dodgsontown Ford; YEF 809–52; YEF 299–300. (*b*) [4986 7523], 180 yd S. of Dodgsontown Ford; YEF 303.

47. Sleet Beck [4962 7689 to 4963 7699], 940 yd at 264° to 910 yd at 270° from Crossings; RS 5371–421.
48. River White Lyne [5109 7322 to 5084 7336], (see Appendix I), 500 yd at 238° from High Mossthorne to 340 yd at 185° from High Parkfoot; YPF 792–934.
49. Whitberry Burn: (*a*) [5203 7408], 225 yd at 241° from Hillend Farm, YFF 720–37. (*b*) 230 yd at 241° from Hillend Farm; YEF 823–4, 357–60. (Spadeadam Limestone overlying Whitberry Band).
50. Rough Grain [5878 8107], 550 yd at 80½° from confluence of Gate Grain and Rough Grain; RS 6076–91 (Whitberry Band).
51. Green's Burn: (*a*) [5836 7030], 380 yd at 212° from Spadeadam Farm; YEF 567–9 (*Composita* limestone). (*b*) tributary 60 yd N. of Spadeadam Farm; YEF 575–7 (Whitberry Band). (*c*) [5826 7028]; YEF 601–4.
52. Stone Beck: (*a*) [5804 6868], 510 yd at 318½° from Spotleybank Farm; YEF 570; He 2712–26. (*b*) [5805 6880], 615 yd S. 8° E. of Torties Farm; YEF 494.
53. Trout Beck [607 703], below Dumblar Rigg; R 2965–74.
54. King Water: (*a*) [6309 7255], 555 yd at 297° from Watch Rigg; YEF 509–15. (*b*) [6295 7231], 650 yd W. of Watch Rigg; YEF 516.
55. Spadeadam No. 1 (Middle Shield) Bore [6164 7041], depth 100 to 375 ft; NEW 4374–529 (see Appendix II).
56. Butter Burn: (*a*) [6114 7421], 485 yd N.W. of Butterburn Hill; YEF 485–7; 543–6 (Whitberry Band). (*b*) [6119 7416], 40 yd W. of loc. 56a; YEF 491, 522–4. (*c*) [6123 7405], 300 yd N. 53° W. of Butterburn Hill; YEF 521, 551–2.

UPPER BORDER GROUP

57. Riding Grain at junction [5545 8705] with Kershope Burn and 100 ft upstream [5548 8706]; YPF 3236–95.
58. Kershope Burn [5310 8560], 30 yd upstream from mouth of Craggy Cleugh; YAF 623.
59. Kershope Burn [5202 8495], 650 yd W. 12° N. of English Kershope; YFF 2749–66.
60. Golden Cleugh: (*a*) [5111 8386] 1190 yd N. 66° E. of Kershope Bridge; YFF 2706–16. (*b*) [5088 8412], 70 yd upstream from confluence with Kershope Burn; YAF 597.
61. Thief Cleugh: (*a*) [4925 8217 to 4926 8206], 865 to 985 yd upstream from confluence with Kershope Burn; YFF 1932–59. (*b*) [4922 8267], 330 yd upstream from confluence with Kershope Burn; YAF 594.
62. Liddel Water: (*a*) [4600 8000], at Pudding Crook; YFF 1096–108 (Dunk Pool Limestone). (*b*) [4619 7998], high on E. bank, 500 yd N. 194° E. of Stonehouse Tower; YFF 1109–13 (Carl Pool Limestone). (*c*) [4693 8107], at mouth of March Sike; YFF 1154–62 (Carl Pool Limestone). (*d*) [4677 8106] 510 yd S.S.W. of Lawston Farm; YFF 1121–53 (Carl Pool Limestone). (*e*) [4728 8140], at mouth of Longcleugh Sike; YFF 1164–79; YAF 568–9. (*f*) [4733 8138], 50 yd upstream from 62e; YFF 1180.
63. Long Cleugh: (*a*) [4786 8130 to 4839 8113], 650 yd at 196° to 900 yd at 154° from Stonegarthside Hall; RN 4078–132 (Burns Beds). (*b*) [4839 8113 to 4882 8089], 900 yd at 154° to 1400 yd at 142° from Stonegarthside Hall; RN 4133–224 (Burns Beds). (*c*) [4805 8119], 300 yd upstream from road bridge; YAF 588. (*d*) [4839 8112], 660 yd E.S.E. from road bridge; YAF 589. (*e*) [4852 8107], 820 yd E.S.E. from road bridge; YAF 590. (*f*) [4763 8145], 215 yd W.N.W. from road bridge; YAF 574.
64. Kitchen Sike [4812 8185 to 4834 8190], from 90 yd at 100° to 350 yd at 85° from Stonegarthside Hall; RN 4319–39.
65. March Sike [4829 8201], 320 yd N. of E. from Stonegarthside Hall; RN 4340–6.

66. Old quarry [4822 8159], 350 yd S.E. of Stonegarthside Hall; YAF 592.
67. Leagair Quarry [4770 7944]; YPF 1905–28; R. 3050–60, 3207.
68. River Lyne: (*a*) [4938 7219], 1860 ft at 353° from Roweltown; YPF 1308–16 (Pink Pool Limestone). (*b*) [4902 7182], 880 ft at 167° from Gibstown; YEF 251; YPF 1331–7 (Kiln Pool Limestone). (*c*) [4894 7182], 750 ft at 170° from Gibstown; YPF 1352–3; YFF 923–36 (Shank Castle Limestone). (*d*) [4883 7182], 700 ft at 193° and 1500 ft at 200° from Gibstown; YPF 7354–82 (between Shank Wood Sandstone and Goat Island Limestone). (*e*) [4901 7179], 800 ft at 163°, and 840 ft at 160° from Gibstown; YPF 1345–51 (Suspension Bridge Limestone). (*f*) [4698 7060], 60 yd S.E. of Shank Castle; YEF 478; RS 5336–45 (Shank Castle Limestone).
69. Rae Burn [4779 7661], 1430 yd at 124° from Liddel Park and up to 125 yd downstream; YAF 532–45.
70. River Black Lyne: (*a*) [4981 7476], 290 yd at 119° from Trough; YEF 298. (*b*) [4972 7386], 650 yd at 257° from Low Dappleymoor Farm; YFF 886–96. (*c*) [4986 7396], 175 yd upstream from 70b; YFF 897–922. (*d*) [4965 7355], 1300 yd N. 86° E. of Mallsburn Farm; YEF 287–8. (*e*) [5008 7451], 530 yd at 205° from Cumcrook Farm; YEF 2013 (Cumcrook Limestone). (*f*) [5112 7608] right bank a few yards downstream from Clattering Ford; M 1142^{F}–82^{F}; YEF 305–9; YFF 741–73; R 2571–605 (Clattering Band). (*g*) [4960 7316], 1340 yd at 104° from Mallsburn Farm; YEF 286. (*h*) [5192 7788], 210 yd N. of Low Todholes Farm; PT 3497–510.
71. Oakshaw Ford Quarry: (*a*) [5120 7605], 300 yd at 200° from Oakshaw road bridge; YFF 798–806 (Oakshaw Limestone). (*b*) [5112 7606], tip material from Oakshaw Coal workings; YFF 774–97.
72. Farloan Sike: (*a*) [5048 7482], 230 yd S. 50° E. of Cumcrook Farm; YEF 314; (*b*) [5038 7453], 350 yd downstream from loc. 16a; YEF 321; YFF 984–1016. (*c*) [5017 7431], 20 yd above confluence with River Black Lyne; YEF 295–7.
73. Crook Gill [4921 7966], 1120 yd at 15° from monument on Green Rigg; RS 5071–90.
74. Parkfoot Sike [5065 7350], 300 yd S.W. of High Parkfoot; YEF 376–82 (Cumcrook Limestone).
75. River White Lyne (see Appendix I): (*a*) [5066 7332 to 5083 7336], north and west of Kaysbank Farm; YPF 964–1104. (*b*) [5020 7337 to 5067 7319], north of Lynecrook Farm; YPF 1105–284. (*c*) [5002 7301], between Goat Island—Lyne thrust and band, 120 yd N.E. of Selbystown; YPF 1286–303.
76. King Water: (*a*) [5968 6858], 750 yd at 70° from Palmers Hill; He 2619–25. (*b*) [5980 6859], 900 yd at 70° from Palmers Hill; He 2626–51. (*c*) [6008 6874], 200 yd at 280° from Snowdon Close; He 2652–63.
77. River Irthing: (*a*) [6897 7168 to 6920 7177], near Bell's Braes, both sides of fault; PT 2776–832. (*b*) [6920 7230 to 6860 7296], upstream from mouth of Sundayburn to a point 1930 yd at 36° from Newhouse; PT 2833–3144 (from Spy Rigg Sandstone to above Leahill Limestone) (see Appendix I, section I 2, Pl. V). (*c*) [6485 6986 to 6626 7064], from 350 yd S. of Wiley Sike House; PT 2664–775 (from Spy Hole Limestone to Leahill Limestone) (see Appendix I; section I 1, Pl. V). (*d*) [6853 7329], 300 yd at 155° from mouth of Linen Sike; PT 3145–81. [see p. 127]. (*e*) [6844 7352], left bank, 300 yd W.N.W. of Tod Hole; PT 3182–327 [see p. 127]. (*f*) [6859 7474], upstream from Lampert to 650 yd N.E. of Lampert; PT 3238–303 [see section, p. 128]. (*g*) [6861 7538], section in tributary stream, 970 yd N.E. of Lampert; PT 3319–46 [see section, p. 128]. (*h*) [6835 7543], right bank, 1000 yd N.E. of Lampert; PT 3347–8 [see section, p. 128]. (*i*) [6824 7595], right bank, 1540 yd N. of Lampert; PT 3408–77 [see section, p. 129]. (*j*) [6811 7566], right bank, 1220 yd at 354° from Lampert; PT 3369–407 [see section, p. 129].
78. Gair Burn: (*a*) [6260 7895], 630 yd at 332° from Irthing Head; DL 898–900.

(*b*) [629 788 to 628 789], 340 to 450 yd above Irthing Head; PT 2625–63. (*c*) [629 786], 225 yd above Irthing Head; PT 2614–23.

79. Jamies Sike [6307 8091], 1350 yd at 108° from bend in county boundary at Horse Head; DL 884–5.
80. Black Cleugh: (*a*) [6725 8070 to 6714 8092], between 250 yd N. of confluence with Channelbush Sike and the Black Cleugh Fault; PT 387–422; DC 234–60; R. 1850–64. (*b*) [6373 8032], 460 yd N. of confluence of Black Cleugh and Chirdon Burn; R 1817–40.
81. Chirdon Burn [6966 8021], 315 yd N. 28° E. from trig. point 1085 on Coom Rigg; PT 429–45.
82. Back Burn: (*a*) [6161 8171 to 6244 8265], from N. of Horse Head to 170 yd above waterfall N.W. of Story's Gairs; PT 446–78. (*b*) [6556 8505], 430 yd upstream from confluence with Binky Burn; PT 103–14.
83. Blackcleugh Burn [6518 8298 to 6527 8249], 720 to 1260 yd S.S.E. of confluence with Humble Burn; DL 971–87.
84. Binky Burn: (*a*) [6590 8388 to 6594 8396], from just above, to 85 yd below. confluence with Humble Burn; DL 996–9, 1005. (*b*) [6615 8303], 1000 yd S. of confluence with Humble Burn; PT 488–501.
85. Little Whickhope Burn: (*a*) [6872 8403 to 6892 8431], between confluence with Byreshield Grains and the Saughy Fault; PT 306–25; DL 946–7, 955–64. (*b*) [6900 8501], Whickhope Linn; PT 203–27; DL 939–45, 951–4. (*c*) [6885 8528] 1370 yd at 134° from Whickhope; DL 932–8.
86. Cranecleugh Burn [6614 8545], 350 yd at 196° from Low Cranecleugh; PT 1–32.
87. Whickhope Burn: (*a*) [6680 8620], 750 to 900 yd N.E. of Low Cranecleugh; PT 42–102. (*b*) [6830 8640], near Whickhope Lodge; PT 115–202; DL 901–16.
88. Yett Burn [6077 8359 to 6036 8305], from 120 yd N. Headless Sike to 100 yd below Slaty Grain; PT 326–86.
89. Reeker Sike [6693 8267 to 6719 8273], 250 to 300 yd S.E. and 490 yd E.S.E. of Reeker Pike; PT 228–51 (see Appendix I).
90. Spadeadam No. 3 Borehole.

LOWER LIDDESDALE GROUP

91. Liddel Water: (*a*) [4444 7900], 125 yd E. of Harelawmill Farm; EB 5649–58. (*b*) [4442 7897], 150 yd at 112° from Harelawmill Farm; EB 5551–69. (*c*) [4446 7881], 230 yd at 133° from Harelawmill Farm; EB 5637–48. (*d*) [4496 7945], 455 yd at 340° from Old Hall; EB 5661–5. (*e*) [4493 7946], 480 yd at 337° from Old Hall; YPF 2152–2200. (*f*) [4449 7872], 250 yd N.N.E. of Hudds Hole Bridge; YAF 551.
92. Nookfoot Sike: (*a*) [4583 7882], 445 yd at 136° from Nookfoot; YPF 2066–80. (*b*) [4594 7957], 640 yd at 40° from Nookfoot; YPF 2084–119, YAF 562–5 (*c*) [4601 7959]. 703 yd at 45° from Nookfoot; YPF 2120–9. (*d*) [4593 7954], 620 yd at 41° from Nookfoot; YPF 2130–5. (*e*) [4593 7952], 590 yd at 44° from Nookfoot; YPF 2137–48.
93. Nookgate Burn [4686 7903], 450 yd W. by N. of Nookgate; YAF 520–3.
94. Hirsthead Sike: (*a*) [4629 7938], 850 yd at 69° from Nookfoot; YPF 1949–66. (*b*) [4626 7940], 825 yd at 67° from Nookfoot; YPF 1980–90. (*c*) [4619 7945], 780 yd at 61° from Nookfoot; YPF 2000–9. (*d*) [4616 7945], 760 yd at 59½° from Nookfoot; YPF 2021–56.
95. (*a*) [4567 7697], Stream, 180 yd W.N.W. of Bessiestown Farm; YAF 509–10. (*b*) [4450 7848], 165 yd up small tributary to Liddel Water at Huddshole Ford; YAF 553–4.
96. River Lyne, [4859 7151], 680 yd at 221° from Gibstown; YEF 483–4; YPF 1383–92 (Goat Island Limestone and overlying shales).
97. Hagg Beck: (a) [4735 7328], 370 yd at 326° from Hallsford; RS 4856–83.

(*b*) [474 743 to 475 739], ¼ mile-long section upstream from road bridge; PT 3511–82.

98. Tipalt Burn: (*a*) [6875 6821], 150 yd S. of Farglow; FMT 58–60 (thin limestone above Denton Mill). (*b*) [6708 6785], 800 yd N.E. of Greengate Well; FMT 61–5 (first limestone above Denton Mill).

UPPER LIDDESDALE GROUP

99. Liddel Water, Penton Linns section [4302 7736 to 4321 7747], from 250 yd at 68° from Knowehead to 85 yd downstream from Penton Bridge. (*a*) EB 4609–39 (about Midway between Harelawhill and Buccleuch limestones). (*b*) EB 4640–41 (Limestone above Harelawhill Limestone). (*c*) EB 4651–87 (Harelawhill Limestone). (*d*) DB 4688–743 (Gastropod Limestone). (*e*) EB 4744–87; EG 5694–508 (between Gastropod and Tombstone limestones). (*f*) EB 4788–93 (Tombstone Limestone). (*g*) EB 4794–9 (Linns Limestone). (*h*) EB 4804–37 (between Linns and Bridge limestones). (*i*) EB 4838–56 (Bridge Limestone). (*j*) EB 4857–9 (between Bridge and Penton limestones). (*k*) EB 4860–905 (Penton Limestone).
100. Liddel Water at Cat Linns [4416 7825], 900 yd at 62° from Shielingmoss Farm: (*a*) EB 5163–82 (Harelawhill Limestone). (*b*) EB 5183–209 (between Harelawhill and Gastropod limestones). (*c*) EB 5212–24 (Gastropod Limestone).
101. Liddel Water at Dormont Pool [4405 7815], 725 yd at 54° from Shielingmoss Farm: (*a*) EB 5153–9 (mudstone above Gastropod Limestone). (*b*) EB 5146–51 (Linns Limestone).
102. Liddel Water: (*a*) [4395 7818], 670 yd at 43° from Shielingmoss Farm; EB 5119–32 (Linns Limestone and underlying sandstone). (*b*) [4370 7738], 465 yd at 148° from Shielingmoss Farm; EB 5063–7 (Harelawhill Limestone).
103. Chapel Burn: (*a*) [4584 7780], 185 yd E.S.E. of Kingfield House; YAF 514–7. (*b*) [4525 7816], 150 yd S.W. of Vicarage; YAF 511–3, 519.
104. Carwinley Burn [4208 7341], 520 yd at 33° from North Lambhill and 60 yd to the N.N.E.; YEF 2002–10 (Penton Limestone).
105. Tipalt Burn [6785 6787], 480 yd W. of Low Tipalt; FMT 76 (Greenhead Bankhouses Limestone).

REFERENCES

ANDERSON, F. W. 1950. Some reef-building calcareous algae from the Carboniferous rocks of northern England and southern Scotland. *Proc. Yorks. geol. Soc.*, **28,** 5–28.

BLACK, M. 1933. The algal sediments of Andros Island, Bahamas. *Phil. Trans. R. Soc.*, ser. B, **12,** 165–92.

BRADLEY, W. H. 1927. Tertiary and Recent freshwater algal reefs. *J. Wash. Acad. Sci.*, **17,** 232–3.

—— 1929. Algal reefs and oolites of the Green River Formation. *Prof. Pap. U.S. geol. Surv.*, 154–G, 203–23.

CLOUD, P. E. 1942. Notes on stromatolites. *Am. J. Sci.*, **240,** 363–70.

DIENER, C. 1925. *Grundzüge der Biostratigraphie*, Franz Deuticke.

EARP, J. R., MAGRAW, D., POOLE, E. G., LAND, D. H. and WHITEMAN, A. J. 1961. Geology of the country around Clitheroe and Nelson. *Mem. geol. Surv. Gt Br.*, i-ix, 1–346.

ENDO, R. 1956. Stratigraphical and palaeontological studies of the later Paleozoic calcareous algae in Japan. X, Fossil algae from the Kwanto and Kitakami Mountains. *Sci. Rep. Saitama Univ.*, ser. B, **2,** 221–48.

FRITSCH, F. E. 1935. *The structure and reproduction of the algae*. Cambridge.

GARWOOD, E. J. 1913a. The Lower Carboniferous succession in the north-west of England. *Q. Jl geol. Soc. Lond.*, **68**, 449–586.

—— 1913b. On the important part played by calcareous algae at certain geological horizons, with special reference to the Palaeozoic rocks. *Geol. Mag.*, dec. 5, **10**, 440–6, 490–8, 545–53.

—— 1914. Some new rock-building organisms from the Lower Carboniferous beds of Westmorland. *Geol. Mag.*, dec. 6, **1**, 265–71.

—— 1916. The faunal succession in the Lower Carboniferous rocks of Westmorland and north Lancashire. *Proc. Geol. Ass.*, **27**, 1–43.

—— 1931. The Tuedian beds of northern Cumberland and Roxburghshire east of the Liddel Water. *Q. Jl geol. Soc. Lond.*, **87**, 97–143.

GEORGE, T. N. 1958. Lower Carboniferous palaeogeography of the British Isles. *Proc. Yorks. geol. Soc.*, **31**, 227–318.

JOHNSON, J. H. 1937. Algae and algal limestone from the Oligocene of South Park, Colorado. *Bull. geol. Soc. Am.*, 48, 1227–35.

—— and KONISHI, K. 1956. Studies of Mississippian algae. *Colo. Sch. Mines Q.*, **51**, 1–131.

JONES, T. R. and KIRKBY, J. W. 1886. On some undescribed species of British Carboniferous ostracods. *Ann. Mag. nat. Hist.* (5) **18**, 249–69.

KALKOWSKY, E. 1908. Oolith und Stromatolith in nord-deutschen Bunt-sandstein. *Z. dt. geol. Ges.*, **60**, 68–125.

KIDSTON, R. 1903. The fossil plants of the Carboniferous rocks of Canonbie, Dumfriesshire and of parts of Cumberland and Northumberland. *Trans. R. Soc. Edinb.*, **40**, 741–834.

—— 1923. Fossil Plants of the Carboniferous rocks of Great Britain. *Mem. geol. Surv. Gt Br., Palaeont.*, **2**, 199–274.

KINDLE, E. M. 1935. Lime-separating algae from subarctic Canada. *Geol. Mag.* **72**, 519–21.

LEE, G. W. 1912. The British Carboniferous Trepostomata. *Mem. geol. Surv. Gt Br., Palaeont.*, **1**, 135–95.

LOGAN, B. W. 1961. Cryptozoon and associated stromatolites from the Recent of Shark Bay, Australia. *J. Geol.*, **69**, 517–33.

—— REZAK, R. and GINSBERG, R. N. 1962. *Classification and environmental significance of stromatolites*. A. and M. College, Texas, 1–23.

LONGSTAFF, J. 1926. A revision of the British Carboniferous Murchisoniidae. *Q. Jl geol. Soc. Lond.*, **82**, 526–55.

LUMSDEN, G. I., TULLOCH, W., HOWELLS, M. F. and DAVIES, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

—— and WILSON, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

MASLOV, V. P. 1935. Contributions to the study of the fossil algae in USSR. *Trans. all-Union Sci. Res. Inst.*, 72.

—— 1937. On the Paleozoic rock-building algae of east Siberia. *Moscow Univ. Lab. Pal. Pub.*, Problems of Palaeontology, 2 and 3, 249–348.

—— 1939. The genus *Collenia*, ibid. 5, 297–305.

MILLER, H. 1887. The geology of the country around Otterburn and Elsdon. *Mem. Geol. Surv. Gt Br.*

MUIR-WOOD, HELEN M. 1928. The British Carboniferous Producti. II *Productus* sensu stricto *semireticulatus* and *longispinus* groups. *Mem. Geol. Surv. Gt Br., Palaeont.*, **3**, 1–127.

—— 1931. Brachiopods from the Tuedian beds of northern Cumberland. *Q. Jl geol. Soc. Lond.*, **87**, 144–54.

NICHOLSON, H. A. 1888. On certain anomalous organisms which are concerned in the formation of some of the Palaeozoic limestones. *Geol. Mag.*, **25**, 15.

PIA, J. 1927. Die Erhaltung der fossil Pflanzen in Hirmer, M., *Handbuch der Palaeobotanik*, Munich and Berlin, **1**, 1–112.

SHARMAN, G. and NEWTON, E. T. 1892. On a new form of *Agelacrinites* (*Lepidodiscus Milleri* n. sp.) from the Lower Carboniferous Limestone of Cumberland. *Q. Jl geol. Soc. Lond.*, **48**, 150.

SMITH, G. M. 1938. *Cryptogamie Botany; Vol. 1: Algae and Fungi.* McGraw Hill, New York.

THOMAS, I. 1914. The British Carboniferous Producti. I. Genera *Pustula* and *Overtonia. Mem. geol. Surv. Gt Br., Palaeont.*, **1**, 197–366.

TWENHOFEL, W. H. 1932. *Treatise on sedimentation*, London.

WEIR, J. 1931. The British and Belgian Carboniferous Bellerophontidae. *Trans. R. Soc. Edinb.*, **56**, 767–861.

WESTOLL, T. S., ROBSON, D. A. and GREEN, R. 1955. A guide to the geology of the district around Alnwick, Northumberland. *Proc. Yorks. geol. Soc.*, **30**, 61–100.

Chapter VIII

PETROGRAPHY OF LOWER CARBONIFEROUS SANDSTONES

General Account

Sandstone members of the Lower Carboniferous in the Northumbrian Trough have, with few exceptions, received little sedimentological and petrographical attention. Robson (1956), in a sedimentary study of the Fell Sandstones and of Cementstone Group sandstones in the Coquet valley, indicated that the main provenance lay to the north-east. A marked degree of uniformity of grade-size throughout the Fell Sandstones (average median granularity about 0·23 mm) and a finer average median granularity (about 0·16 mm) of the Cementstone Group sandstones were also shown (*ibid.*, fig. 9). Robson (*ibid*, p. 254) noted further that the latter sandstones can generally be distinguished from the Fell Sandstones by their relatively conspicuous content of apatite and muscovite, persistence of pink garnet, and paucity of purple zircon, although these differences are diminished by a 'mixed zone' in the basal Fell Sandstones.

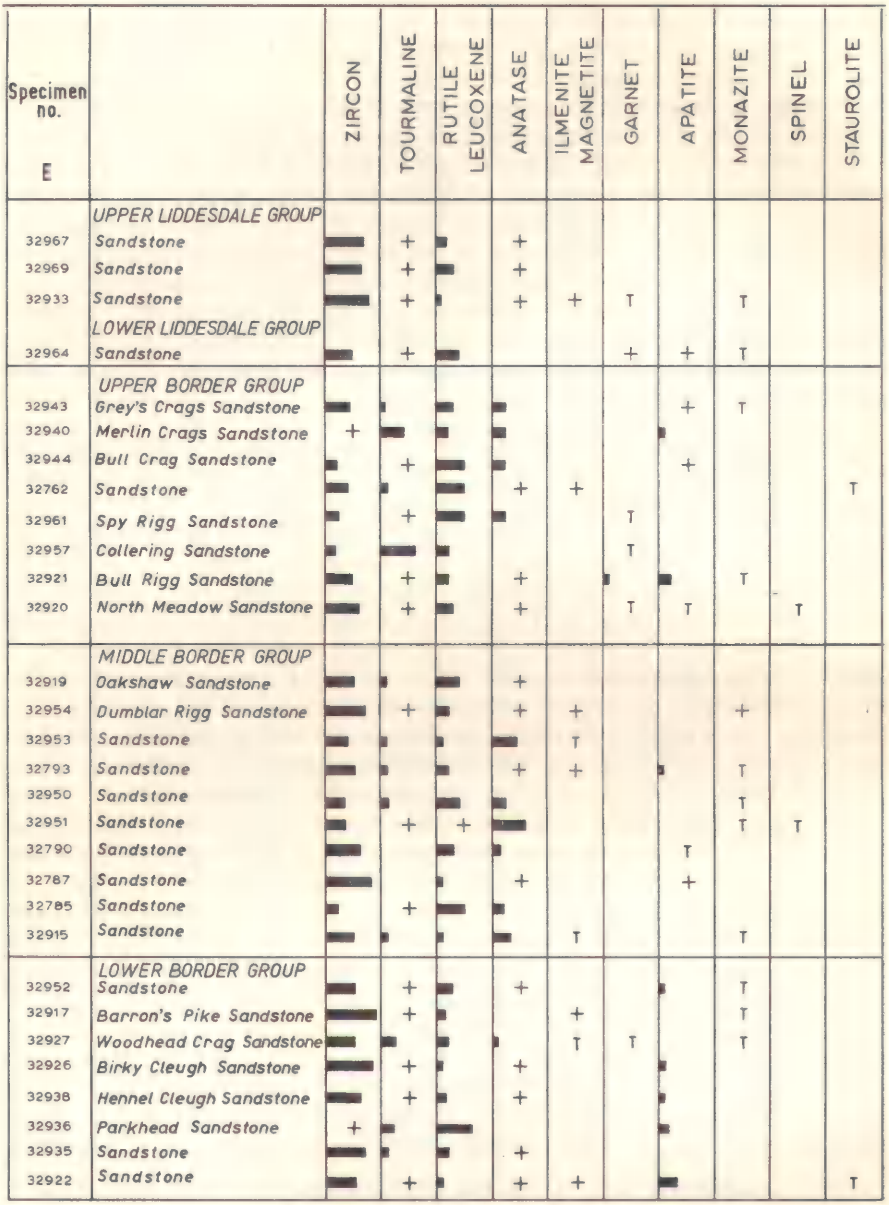
The Fell Sandstones of the Brampton district are described by Trotter and Hollingworth (1932, p. 25) as typically 'pink, coarse and devoid of mica, but some beds do not differ from the normal grey, medium-grained, micaceous sandstones which are found throughout the Carboniferous'. Mica is also sparse in the Fell Sandstones of the ground around Kielder, north of the Bewcastle district, but Fowler (1966, p. 68) there finds most of the sandstones to be medium-grained, weathering yellowish, buff or rarely greenish, with local red or chocolate-coloured staining and with diagnostic intercalations of variegated mudstones or 'marls'.

Present studies of some seventy specimens of arenaceous rocks ranging stratigraphically throughout the Lower Carboniferous and geographically over much of the district have been mainly confined to their textures and mineralogical composition. Detailed petrographical descriptions include references to the relevant stratigraphical accounts. In general, the arenaceous rocks show overall uniform grading, the predominant grades being of mainly fine to medium (0·1 to 0·2 mm) sand. There is apparently no variation of grading with geographical distribution. Sandstones of the Lower Border Group are, on average, a little finer grained than those of the Middle Border Group, which are in turn slightly finer than sandstones of the Upper Border Group. Specimens from the Lower and Upper Liddesdale groups fall within these ranges. Sorting is generally markedly high. Clastic grains are commonly tightly packed and cementation is mainly attributable to secondary silica or carbonates, though intergranular kaolinite and other clay minerals are common in some specimens.

In composition, the arenaceous rocks are mainly subarkosic with plentiful igneous quartz and subordinate metamorphic quartz, polygranular quartz, and resistate rock particles, plagioclase (commonly oligoclase), perthite, orthoclase and microcline. Allogenic carbonates are commonly present. Labile rock particles are generally sparse. While in the catchment areas of the rivers Irthing, South Tyne and Lyne there appears to be no discernible variation of lithology with stratigraphical horizon, in the drainage area of the River North Tyne, feldspar-free quartzitic sandstones occur mainly in the Upper Border Group. At Barren Crags [6495 7982], however, at the southern margin of the North Tyne drainage area, sandstones in the basal part of the Upper Border Group are more sub-arkosic in character. Micas are common in most of the sandstones examined with little difference between sandstones of the Lower and Middle Border groups, contrary to those described in the Brampton, Kielder and Coquet districts where the sandstone units are more massively developed. Carbonaceous particles, rootlets and films are commonly present, together with other evidence of shallow water deposition such as current bedding, worm-tubes, worm-tracks and ripple-marks.

Accessory mineral suites show certain common characteristics over the stratigraphical range (Fig. 31). Of the species listed, the polymorphs of titania, especially anatase and leucoxene are commonly authigenic. There appears, however, to be a paucity or absence of apatite and garnet in the Middle Border Group, and this would seem to accord well with the conclusions of Robson (1956, p. 254) in view of the imperfect correlation of the group with the Fell Sandstones of his area (p. 9). There is, however, considerable variation in the heavy mineral suites as a whole, and exhaustive separations are necessary to confirm this tentative conclusion. Zircon, commonly the predominant accessory mineral, varies from polycyclic, well-rounded grains (colourless, brownish and purple) to little-abraded crystals, mainly colourless. Tourmaline similarly varies in degrees of abrasion. The commonest pleochroism schemes are (i) O = dark brown to black, E = very pale brown to colourless; (ii) O = dark green (commonly olive green), E = pale pink to colourless; (iii) O = dark blue, E = colourless. An acid igneous provenance (Krynine 1946 p. 68), is thus indicated by the species of tourmaline recorded. Rutile forms very dark reddish brown and yellowish brown prisms ranging from rounded to angular, and sparse geniculate twins. Anatase is commonly in subopaque aggregates or clear, single, tabular yellowish crystals, exhibiting rather anomalous purplish blue interference colours under crossed polars. Turbid anatase grades into opaque leucoxenic material, which probably consists mainly of rutile. Garnet occurs rarely as angular, step-etched, pale pink to colourless grains with refractive index (*n*) near 1·79. Apatite is relatively conspicuous in suites from the Lower and Upper Border groups. Ilmenite and magnetite are generally sparse. Trace constituents include yellowish monazite, brown staurolite and pale blue spinel.

Certain arenaceous rocks from the North Tyne catchment area are conspicuous on account of a strong greenish colour derived from chlorite. These rocks range from the Lower to the Middle Border groups and occur at the following localities: south bank of Lewis Burn [5846 8576] and below Marven's Cleugh [5887 8613]; Marven's Cleugh [5836 8631]; Little Marven's Cleugh [5870 8629] and in the western bank of Yett Burn [6117 8501]. The chlorite forms coarse, irregular microcrystalline patches and finely acicular intergranular aggregates commonly projecting into the clastic quartz grains (Plate XIII, fig. 2). Secondary silica appears to have formed subsequent to the deposition of the chlorite. Clastic grains of lava particles are strewn amongst corroded quartz and



Specimen no. E		ZIRCON	TOURMALINE	RUTILE LEUCOXENE	ANATASE	ILMENITE MAGNETITE	GARNET	APATITE	MONAZITE	SPINEL	STAUROLITE
	UPPER LIDDESDALE GROUP										
32967	*Sandstone*	▬	+	▬	+						
32969	*Sandstone*	▬	+	▬	+						
32933	*Sandstone*	▬	+	▬	+	+	T		T		
	LOWER LIDDESDALE GROUP										
32964	*Sandstone*	▬	+	▬			+	+	T		
	UPPER BORDER GROUP										
32943	*Grey's Crags Sandstone*	▬	▬	▬	▬			+	T		
32940	*Merlin Crags Sandstone*	+	▬	▬	▬			▬			
32944	*Bull Crag Sandstone*	▬	+	▬	▬			+			
32762	*Sandstone*	▬	▬	▬	+	+					T
32961	*Spy Rigg Sandstone*	▬	+	▬	▬		T				
32957	*Collering Sandstone*	▬	▬	▬			T				
32921	*Bull Rigg Sandstone*	▬	+	▬	+		▬	▬	T		
32920	*North Meadow Sandstone*	▬	+	▬	+		T	T		T	
	MIDDLE BORDER GROUP										
32919	*Oakshaw Sandstone*	▬	▬	▬	+						
32954	*Dumblar Rigg Sandstone*	▬	+	▬	+	+			+		
32953	*Sandstone*	▬	▬	▬	▬	T					
32793	*Sandstone*	▬	▬	▬	+	+		▬	T		
32950	*Sandstone*	▬	▬	▬	▬				T		
32951	*Sandstone*	▬	+	+	▬				T	T	
32790	*Sandstone*	▬		▬	▬			T			
32787	*Sandstone*	▬		▬	+			+			
32785	*Sandstone*	▬	+	▬	▬						
32915	*Sandstone*	▬	▬	▬	▬	T			T		
	LOWER BORDER GROUP										
32952	*Sandstone*	▬	+	▬	+			▬	T		
32917	*Barron's Pike Sandstone*	▬	+	▬		+			T		
32927	*Woodhead Crag Sandstone*	▬	▬	▬	▬	T	T		T		
32926	*Birky Cleugh Sandstone*	▬	+	▬	+			▬			
32938	*Hennel Cleugh Sandstone*	▬	+	▬	+			▬			
32936	*Parkhead Sandstone*	+	▬	▬				▬			
32935	*Sandstone*	▬	▬	▬	+						
32922	*Sandstone*	▬	+	▬	+	+		▬			T

KEY

0 50 100

▬ *% of grain-count to nearest 10%*

+ *< 5%*

T *trace*

FIG. 31. *Distribution of heavy accessory minerals in some Lower Carboniferous sandstones*

feldspar grains, together with common granules of leucoxene and crystals of anatase. The rock assumes a subgreywacke texture and composition, and indicates likely nearby contemporaneous igneous activity. No comparable rocks were recorded by Diane C. Knill (*in* Lumsden and Wilson 1961, pp. 73–4) in the Glencartholm Volcanic Beds, penetrated in the Archerbeck Borehole. Similar chloritized sandstones were found, however, in Spadeadam No. 4 (Grey Mare) Bore (p. 215). A conglomerate recorded at a depth of 162 ft in this borehole has been impregnated with pyrite, hydrocarbons and also much granular kaolin.

The arenaceous rocks grade, through the addition of derived carbonate particles, into sandy calcarenites, commonly organic (Plate XIII, fig. 3). Authigenic carbonates are commonly present especially ferroan dolomite, which replaces the resistates in varying degrees (Plate XIII, figs. 5 and 6), and in one specimen, is associated with leucoxene or anatase.

In conclusion, the arenaceous specimens described, generally indicate derivation from a predominantly acid igneous provenance furnishing periodically supplies of immature, labile-rich subarkosic detritus, at times diluted with calcarenitic and other material. Robson (1956, p. 249) postulated a north-easterly provenance for the Fell Sandstones in the Coquet valley, deposited from a south-westerly flowing river. Some geographical or climatic change at the end of Lower Border Group times (*ibid.*, p. 256) is also indicated in the present district. It is interesting to note that the Ashfell Sandstone examined from Swindale Beck [NY 7611 2066], Westmorland, is lithologically closely similar to the general run of subarkosic sandstones described above. Garwood (1931, p. 101) notes that the Ashfell Sandstone occurs at approximately the same horizon as the Fell Sandstone. In fact, the prevalence, although in small amount, of microcline in the subarkoses described, perhaps, indicates some similarity of provenance—a Caledonian continent (Rayner 1953, p. 297)—as the considerably more massive sandstones of the Millstone Grit Series (cf. Gilligan 1920, p. 275) to the south. A further change is suggested at the end of Middle Border Group times, at least in the north-eastern part of the district, with the deposition of relatively mature quartz-sandstones. The difference in depositional environment between the north-east and south-west parts of the district, established on palaeontological and stratigraphical evidence, is not reflected in the arenaceous members of cyclothems.

DETAILS

LOWER BORDER GROUP: LYNEBANK BEDS

The lowest sandstone examined microscopically is the bed which lies midway between the Ellery Sike and Rawney limestones and which crops out in the River White Lyne [5455 7571] just east of the mouth of Ellery Sike (p. 22). It is a thinly bedded, micaceous, fine-grained, greyish buff rock (E 32922), composed of well-sorted (median granularity 0·08 mm) angular quartz and potash feldspars commonly aligned parallel to the bedding, with abundant interstitial muscovite and illite shreds, chlorite and sparse glauconite. Heavy accessory minerals (Fig. 31) include common zircon (rounded to sharply euhedral crystals), apatite (clear, subangular), tourmaline (prismatic with O = dark olive green-brown, E = colourless), rutile (slender prisms of dark reddish brown and yellowish brown colour), sparse anatase (pale green-brown), ilmenite, staurolite, and a trace of sapphire. A subarkosic affinity with this specimen is apparent in the thin sandstone lying some 20 ft below the Rawney Limestone (p. 23) and cropping out in

Bothrigg Burn [5481 7597]; the clastic components of this sandstone (E 32923) consist of igneous quartz, orthoclase, microcline and plagioclase with muscovite and hydrobiotite. Dolomite (refractive index $\omega = 1{\cdot}684$) and calcite are abundant, comprising up to 50 per cent of the rock by volume. The clastic grains show varying degrees of carbonate replacement, advanced stages being shown by palimpsests of feldspars, remnants of quartz and other minerals in optical continuity. This evidence suggests that some of the original arenaceous component has been removed through extensive replacement either during or after diagenesis. Pyrite crystals and granules are conspicuous with opaque leucoxene and carbonaceous particles.

The only other sandstone of note in the Lynebank Beds lies 1000 ft higher. A specimen (E 32934) from Kirk Beck [5545 7438] is flaggy, well-bedded and conspicuously micaceous on bedding planes. Subarkosic constituents (igneous and lesser metamorphic quartz, microcline, oligoclase, perthite and orthoclase) with polygranular quartz and detrital muscovite are tightly packed and well graded. Scattered calcite grains occur interstitially. Heavy accessory minerals include zircon, tourmaline (O = olive green, E = colourless), rutile, leucoxene, anatase and a trace of garnet. Grains of microbotryoidal hydrocarbon and collophane are sparse.

LOWER BORDER GROUP: BEWCASTLE BEDS

The lowest Bewcastle Beds sandstone, lying between the Bogside and Kitty Beck limestones, was sampled in Kirk Beck [5577 7436]. In thin section (E 32935) it is seen to be a dolomitic and calcitic subarkose with a median granularity of 0·2 mm. Ferroan dolomite ($\omega = 1{\cdot}694$) forms replacement textures and porphyroblastic outlines against the clastic grains. Veinlets of non-uraniferous hydrocarbon (probably a pyrobitumen) and granular pyrite are locally developed. Heavy detrital minerals include zircon, elongated brown and pinkish brown rutile, and subhedral tourmaline (O = dark green, E = colourless).

The Parkhead Sandstone in Kirk Beck [5604 7439] is a flaggy, micaceous even-grained (0·2 mm) subarkose bordering on an arkose with a conspicuous proportion of fresh orthoclase, microcline and oligoclase (E 32936). Elongated grains are conspicuous in subparallel alignment, being tightly packed and showing microstylolitic contacts. Detrital muscovite and illite occur in the matrix with conspicuous calcite. Heavy minerals include angular to rounded tourmaline (O = dark green, E = colourless; O = dark blue, E = pinkish brown; O = greenish black, E = colourless–pink), angular fresh apatite, granular leucoxene, and dark reddish brown acicular rutile.

The Hennel Cleugh Sandstone from Kirk Beck [5629 7446] is closely comparable in consisting of even-grained (0·2 mm), closely packed quartz, conspicuous feldspars (microcline, cryptoperthite, orthoclase and oligoclase) and polygranular quartz, showing microstylolitic contacts and some secondary silicification (E 32938: Pl. XIII, fig. 1). The sparse matrix includes illite, muscovite, chlorite and calcite, the latter marginally replacing quartz. Heavy accessory minerals include: colourless subrounded to euhedral grains and well-rounded purplish grains of zircon, subangular tourmaline (O = dark olive green to black, E = pale green to colourless), dark reddish brown and more transparent yellowish rutile, subangular coarse (0·2 mm) apatite, authigenic dark brown tetragonal tablets of anatase and leucoxene.

The central part of the next sandstone in upward sequence—the current-bedded Plantation Sike Sandstone—was sampled in White Beck [5715 7369]. The specimen (E 32925) is a laminated carbonaceous and micaceous calcitic fine-grained sandstone in which quartz (chiefly igneous) and feldspars (orthoclase, microcline, acid plagioclase) are loosely packed in abundant matrix composed of iron-stained illite, muscovite, and chlorite with calcite cement and streaks of carbon. Tourmaline (O = olive green, E = colourless), anatase and zircon are sparse accessories.

LOWER BORDER GROUP: MAIN ALGAL BEDS

The sandstone overlying the Birky Cleugh Limestone in White Beck [5763 7333] is even grained (0·15 mm), pale grey and conspicuously micaceous, with closely packed quartz (mainly igneous), orthoclase, microcline and plagioclase, showing microstylolitic contacts (E 32926). The matrix includes subopaque leucoxene, hydrobiotite, calcite and darker dolomite. Part of the carbonate is detrital. Accessory minerals include rounded, colourless and purple zircon, dark reddish brown, angular to subrounded rutile, angular tourmaline (O = dark greenish black, E = pale pinkish brown), coarse angular apatite, brown anatase and leucoxene.

In the Woodhead Crag Sandstone cropping out in White Beck [5788 7324] feldspars are less prominent (E 32927). It is a hard, quartzitic, fine- to medium-grained (0·2 mm) sandstone in which quartz grains are closely packed with microstylolitic contacts and secondary overgrowths. Rock particles, especially quartzite, are subordinate. Heavy accessory minerals include polycyclic well-rounded, and euhedral colourless and purple zircon, well-rounded and sharply prismatic tourmaline (O = dark olive green to black, E = colourless to pale green; O = very deep yellowish brown, E = pale yellow), deep reddish brown prisms and geniculate twins of rutile, brown anatase, and a trace of garnet.

LOWER BORDER GROUP: CAMBECK BEDS

The lower leaf of the Barron's Pike Sandstone, sampled in Melefarm Beck [5554 7139] is composed of tightly packed, well-sorted (averaging 0·1 mm) quartz, oligoclase, microcline, orthoclase and rock particles, the quartz showing secondary overgrowths and microstylolitic contacts (E 32924). Heavy minerals include zircon, rutile, anatase and leucoxene. Calcite is prominent as a cement in the present specimen, marginally replacing the clastics. Pyrite granules are also present.

The upper leaf, sampled in Whitberry Burn [5220 7403], is a similar rock in which closely packed, well-graded (0·1 mm) resistates show microstylolitic contacts and some preferred orientation parallel to the bedding (E 32917). The well-bedded nature of this sandstone is further emphasized by plentiful muscovite on bedding planes. Igneous, and lesser metamorphic, quartz, prominent fresh feldspars (microcline, orthoclase, plagioclase) and rock particles (quartzite mainly) comprise most of the rock with sparse intergranular illite and some ferric oxide. Heavy minerals include well-rounded grains and euhedral crystals of colourless and purplish zircon, ragged grains of tourmaline (O = dark bottle green to brownish green, E = colourless), reddish brown, rounded to subangular prismatic rutile, and minor ilmenite.

The sandstone above the *Syringothyris* Limestone in Whitberry Burn [5208 7408] is in the main similar to the previous sandstone, being a well-graded (0·15 mm), closely packed subarkose with predominant igneous quartz, conspicuously fresh, angular to well-rounded microcline and orthoclase, minor quartzite and cherty silica (E 32916). The matrix consists of granular kaolinite and dusty leucoxene. A modal analysis gave, in volume per cent: quartz 90; orthoclase 2; microcline 1; kaolinite 2; rock particles 1; secondary silica 3; illite ½; biotite, ferric oxide and heavy minerals (zircon, tourmaline) ½.

A sandstone lying near the top of the Lower Border Group and cropping out on the south bank of the Lewis Burn [5846 8576] is greyish green and fine- to medium-grained (E 32952: Pl. XIII, fig. 2). It is poorly graded, with angular clastics (quartz, microcline, orthoclase, polygranular brownish silica) partly cemented by secondary silica and partly scattered in a pale brown to green fibrous chlorite-rich matrix. The chlorite marginally replaces the clastics and in places apparently predates the deposition of secondary silica. An X-ray powder photograph (NEX 154) of the whole rock showed major quartz, and chlorite. The chlorite is strongly pleochroic with X (normal to the cleavage) = pale brown; Z = deep green. Heavy minerals include rounded prisms and acicular crystals of zircon, subangular to rounded tourmaline (O = dark green, E = colourless), subangular to well-rounded apatite, squat pale brown tabular anatase, dark brown and yellowish brown prisms and geniculate twins of rutile, and conspicuous aggregates of leucoxene.

MIDDLE BORDER GROUP

A sandstone near the base of the Middle Border Group supports the bridge crossing Whitberry Burn [5192 7408]. It is hard, compact and well graded (0·2 to 0·3 mm). In section (E 32915), an interlocking mosaic of mainly igneous quartz, microcline, orthoclase and minor cherty silica, shows secondary silicification and incipient microstylolitic contacts. Muscovite is prominent on bedding planes, while a little kaolinite and hematite occur in the interstices.

Three sandstone specimens were examined from Yett Burn [6138 8645] 480 yd E. of High Long House. One (E 32784) is a calcitic fine sandstone (0·06 to 0·08 mm granularity), with elongated grains in parallel array. Fine micas are conspicuous on bedding planes and in the matrix, including muscovite, biotite and chlorite. Calcite forms interlocking, recrystallized coarse masses and fine dusty aggregates. Heavy minerals include zircon, apatite and a trace of blue spinel. A second specimen (E 32785) is well-bedded with fine micas on bedding planes and large (2 to 3 cm) vughs are lined with quartz and dark brown chlorite (X-ray powder photograph NEX 212). This sandstone passes into a medium brown zone which in section shows abundant interstitial, dusty, untwinned feldspar. An X-ray powder photograph (X 3859, A) by Mr. B. R. Young of this zone showed abundant quartz and feldspar, and minor kaolinite and chlorite. The clastics are subangular quartz and subordinate feldspars (microcline, orthoclase), ranging between 0·06 and 0·2 mm. The third sandstone (E 32786) is pale grey and contains little interstitial feldspar. Heavy minerals include rounded to subhedral colourless and purple zircon, subangular tourmaline (O = dark green to black, E = pale brown), turbid authigenic clusters of fine anatase, dark brown rutile, and much opaque leucoxene.

A sandstone forming a waterfall [5836 8631] in the first tributary on the north-eastern side of Marven's Cleugh is a hard, buff-grey, very porous rock (E 32951) containing fairly graded (0·1 to 0·6 mm, average granularity 0·2 mm), closely packed quartz, microcline, orthoclase and conspicuous rock particles including quartzite, cherty silica, possible lava granules and vein-quartz. Secondary silica is the main cement. An abundant matrix consists largely of golden yellow-brown chlorite (X-ray powder photograph NEX 153), illite and ferric oxide. A specimen (E 32950) taken approximately 12 ft higher at the same locality, is closely similar in lithology. Both are subarkosic, the higher specimen containing labile rock particles indicating a subgreywacke affinity. Heavy minerals separated from the latter sandstone include rounded, colourless, yellow and purple zircon, rounded prismatic tourmaline (O = dark green-black, E = pale pinkish brown; O = very dark brown, E = pale brown; O = deep blue), rounded reddish brown rutile prisms, conspicuous colourless to pale yellow partly leucoxenized anatase tablets, and much opaque leucoxene.

A sandstone obtained from the west bank of Yett Burn [6117 8501], 1610 yd S. of High Long House, is a homogeneous, greenish grey fine-grained rock (E 32792) closely resembling a neighbouring sandstone (E 32952) described from the Lower Border Group (p. 213). Corroded clastic grain margins are similarly developed and the overall mineral compositions are comparable. Pale brown to green matrix consists chiefly of chlorite (X-ray powder photograph NEX 3) and accounts for the overall green colour of the sandstone. There are sparse grains of colourless and purple zircon.

Two specimens (E 32793, 32794) of greyish green fine sandstone from the south bank of Lewis Burn [5887 8613], below Marven's Cleugh, closely resemble those described above. They consist of well-graded (0·1 to 0·2 mm) subangular, marginally corroded quartz, microcline, plagioclase, orthoclase and rock particles (quartzites, chert, felsitic and other grains of volcanic origin) set in a matrix containing much chlorite and muscovite.

A sandstone (E 32953) from Little Marven's Cleugh [5870 8639] is less well-graded than the above, ranging from 0·08 to 0·6 mm, with clusters of interlocking clastic grains (quartz, microcline, orthoclase, cherty silica, quartzite and probable volcanic particles) scattered among much clayey matrix—mainly green-brown chlorite.

All the greenish grey specimens above (E 32952, 32792–4) share certain common characteristics—mineral composition, abundance of chlorite, grading and replacement textures. Some clastic material of likely volcanic origin is present, but whether the chlorite can be attributed to a similar source is uncertain.

Five specimens from Spadeadam No. 4 Bore at Grey Mare (Appendix II, p. 338) illustrate some lithological variations. The first (E 33394; depth 80 ft) is a purplish, pyritized calcilutite composed very largely of fine-grained calcite with scattered, partly replaced clastic quartz grains (2 to 3 mm), flakes of muscovite and streaks of pyrite granules. A silty, chloritic and calcitic mudstone (E 33395; depth 120 ft) contains prominent red hematite nodules which appear to replace the host-rock. The latter consists of abundant angular clastic quartz (0·02 to 0·08 mm) scattered in a base of chlorite, illite (including glauconite), muscovite and calcite, with ferric oxide staining. The hematite nodules are elongated along the bedding planes and appear to have formed prior to the deformation of the rock. A coarse conglomerate (E 33396; depth 162 ft) consists of phenoclasts (up to 3 × 0·5 cm) of fine calcarenitic, pyritized sandstone, silty limestone and jasper set in a matrix of medium- to coarse-grained, rounded sand of quartz and feldspars. The matrix is cemented mainly by kaolinite with some calcite and siderite. The kaolinite and pyrite appear to have been introduced metasomatically. Secondary gypsum is present. A complex specimen (E 33397, A) of bedded white and green sandstone, siltstone and mudstone, displays prominent interconnecting ribs of finely micaceous sandstone occupying cracks in the underlying mudstone and siltstone. The paler coloured sandstone consists largely of angular quartz in a matrix of calcite and chlorite. The green sandstone ribs consist of closely packed, medium grade (0·2 to 0·3 mm) quartz with secondary overgrowths in places, subordinate feldspars, interstitial calcite, leucoxenic aggregates, muscovite, illite and chlorite. Coarse feldspars may be partly authigenic. An X-ray powder photograph (NEX 238) of the clay fraction showed major chlorite and illite, which have marginally replaced the clastic grains, particularly feldspar. The lowest specimen (E 33398; depth 244 ft) shows a transition from dark grey shale to brecciated, and partly replaced, pinkish grey porcellanous silty dolomite, veined with pyrite and hydrocarbons. The microcrystalline dolomite is also veined by slightly coarser calcite. Sandy calcarenite composed of poorly sorted (0·06 to 0·3 mm) quartz, feldspar, derived organic particles of carbonate and phosphate, in a matrix of equigranular carbonate, replaces the porcellanous dolomite.

The Dumblar Rigg Sandstone, sampled in Stone Beck [5771 6831], is well bedded with fairly well sorted, mainly fine-sand grade (0·1 mm) clastics showing some secondary silicification with a matrix composed of illite (E 32954). Igneous, and subordinate metamorphic, quartz and polygranular quartz particles are the prominent detrital constituents. Heavy minerals include colourless and purple zircon grains and prisms, commonly with acicular inclusions, dark red-brown and yellow-brown rutile, yellow tabular anatase, leucoxene, subrounded tourmaline (O = dark blue, E = colourless; O = dark green, E = pale pink; O = dark brown–black, E = colourless), and ilmenite.

The lower and upper parts of the Oakshaw Sandstone were sampled in the River Black Lyne [respectively 4996 7530 and 4985 7513]. A specimen (E 32918) from the lower is a quartzitic fine-grained sandstone (0·1 mm) composed predominantly of closely packed, interlocking and secondarily silicified quartz, with subordinate polygranular quartz. The upper (E 32919) is less well-sorted, but similarly consists of a mosaic of interlocking quartz grains (0·08 to 0·4 mm; median granularity 0·2 mm) and subordinate quartzite, cherty silica and intergranular muscovite. Heavy minerals include rounded to euhedral, colourless and purple zircon, dark reddish brown rutile crystals, subangular prisms and well-rounded grains of tourmaline (O = very dark brown to dark green), yellow tablets of anatase, and much leucoxene.

UPPER BORDER GROUP: SOUTHERN AND WESTERN AREAS

The North Meadow Sandstone in the River Black Lyne [4990 7498] is hard, compact and well-graded (averaging 0·2 mm) with interlocking igneous quartz showing secondary overgrowths and microstylolitic contacts, plagioclase, microcline, orthoclase and polygranular quartz (E 32920). Illite, muscovite and a trace of glauconite occur in the matrix. Heavy minerals include dark reddish brown and yellowish rutile, rounded to angular tourmaline (O = dark olive green, E = colourless; O = black, E = pink; O = blue; E =

Explanation of Plate XIII

Photomicrographs of sedimentary rocks in the Lower Carboniferous

Fig. 1. Quartzitic subarkosic sandstone (E 32938), Kirk Beck [5629 7445], Bewcastle Lower Border Group. Hennel Cleugh Sandstone.

Evenly sorted, closely packed, angular to subrounded quartz, microcline, oligoclase, rock particles, are mainly cemented by secondary silica with a little replacive calcite. Partly crossed polars, × 72

Fig. 2. Chloritized sandstone (E 32952), Lewis Burn [5846 8576].
Lower Border Group

Poorly graded, angular quartz, potash feldspars and rock particles (a proportion being of volcanic origin), are set in a chloritic matrix, resembling subgreywacke texture. The chlorite, which has probably been introduced metasomatically, marginally replaces the clastic grains.
Partly crossed polars, × 50

Fig. 3. Sandy calcarenite (E 32958), River Irthing [6542 6960].
Upper Border Group about 20 ft below the Poppingstone Sandstone.

Angular to subrounded, partly replaced clastic grains are scattered in a predominantly calcarenitic matrix composed of foraminifera, brachiopods, gastropods, and crinoid stems, with calcite cement and sparse, rounded grains of hydrocarbon (black, upper left field). Partly crossed polars, × 50

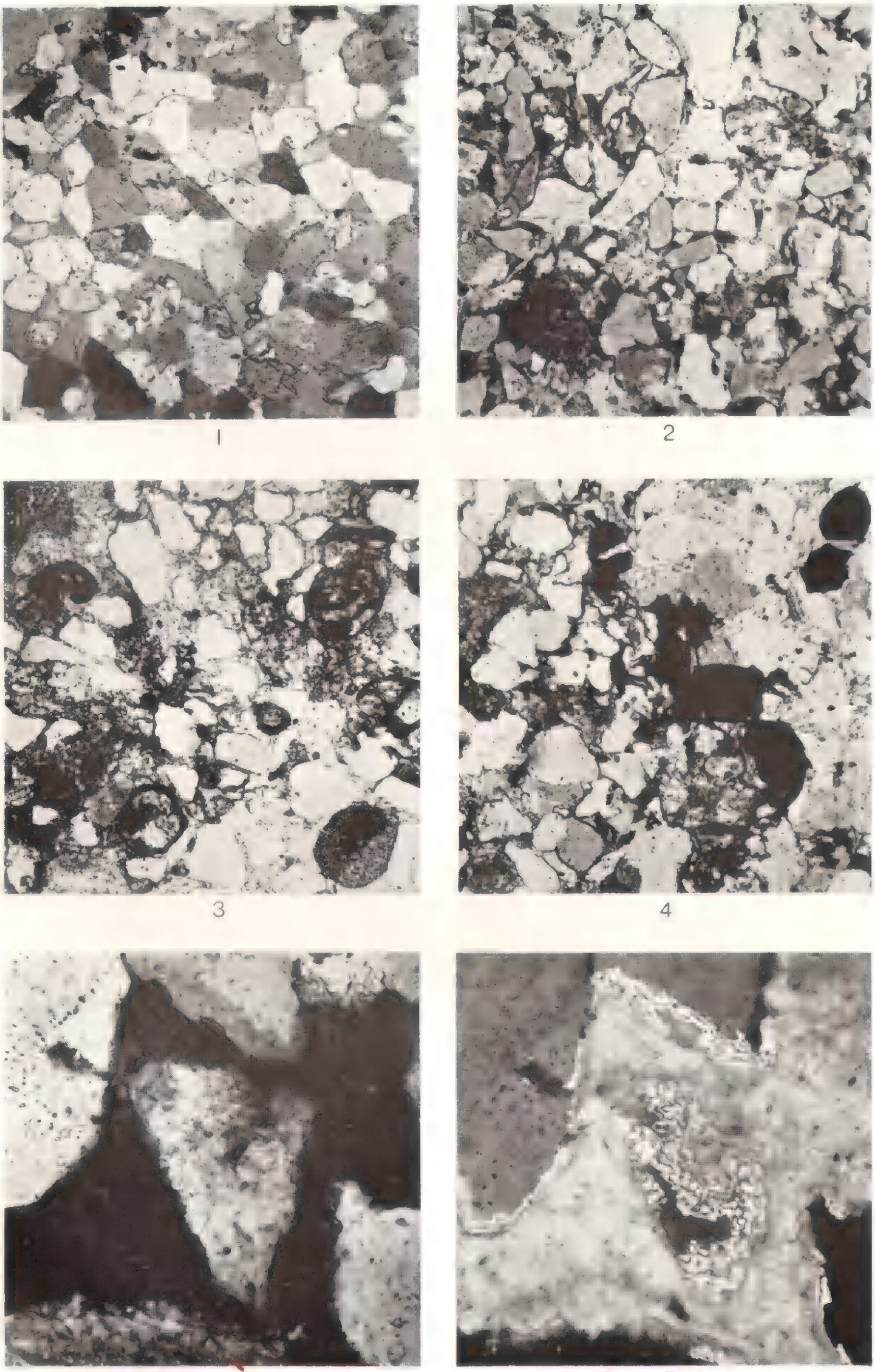
Fig. 4. Quartzitic sandstone (E 32933), Liddel Water [432 774].
Upper Liddesdale Group–Bridge Sandstone.

Subarkosic sandstone contains granules of microbotryoidal hydrocarbon (black, opaque) which replaces the clastic grains, and is paragenetically associated with baryte (medium grey, turbid, mainly upper left of field). Both hydrocarbon and baryte occur in a micaceous parting, with interstitial leucoxene and ferric oxide. Partly crossed polars, × 52

Figs. 5, 6. Dolomitized subarkosic sandstone (E 32956), R. Irthing [6431 6971].
Upper Border Group. Green Grove Sandstone.

Scattered clastic grains are cemented mainly by slightly ferroan dolomite (refractive index $\omega = 1{\cdot}696$). The clastics are extensively replaced by the dolomite, and these two fields illustrate, under crossed polars, the ghost-outlines of a nearly completely dolomitized quartz grain. In fig. 5 the dolomite is in the extinction position, the ghost quartz being apparently uureplaced. In fig. 6, however, the true extent of the replacement is shown, the dolomite being in the 45° position. Both figs. × 306

PLATE XIII



1 2 3 4 5 6

PHOTOMICROGRAPHS OF SEDIMENTARY ROCKS IN THE LOWER CARBONIFEROUS

colourless), colourless and purple, rounded zircon, yellow tablets of anatase, leucoxene and traces of step-etched garnet, spinel and apatite.

A specimen (E 32921) of the Bullrigg Sandstone from the River Black Lyne [5000 7456] is unevenly bedded, with black carbonaceous staining and scattered muscovite flakes on bedding planes together with markings which are perhaps of organic origin. In section, angular quartz, microcline, plagioclase and rock particles are roughly aligned parallel to the bedding, together with muscovite flakes. Carbonates are conspicuous in the matrix and refractive index measurements ($\omega = 1{\cdot}690$ to $1{\cdot}696$) indicate a range between dolomite and ferroan dolomite. Porphyroblastic carbonate replaces quartz in varying degree. Heavy minerals include colourless euhedral and subangular zircon, subangular tourmaline (O = dark green to dark brown; E = colourless), dark reddish brown angular rutile, step-etched colourless angular garnet, prominent subrounded apatite, and a trace of anatase.

The Crammel Linn Sandstone, sampled at the linn [6403 6967] is even-grained (0·15 mm) with muscovite flakes on bedding planes (E 32955). Clastic grains—quartz, microcline, orthoclase and cloudy rock particles—are closely packed and secondarily silicified in places. (See p. 299.)

The Green Grove Sandstone, similarly sampled from a waterfall section [6431 6971] in the River Irthing, is well graded (averaging 0·1 mm) and contains igneous and metamorphic quartz, quartzite, microcline and orthoclase scattered in an abundant carbonate matrix consisting chiefly of a ferroan dolomite (refractive index $\omega = 1{\cdot}696$). This extensively replaces the clastic grains (E 32956; Pl. XIII, figs. 5 and 6).

The next sandstone in upward sequence in the River Irthing [6440 6972] is the Collering Sandstone. The sampled rock (E 32957) is a little coarser (averaging 0·3 mm) than the Green Grove Sandstone, though similarly well-graded. Quartz, polygranular quartz (quartzite, cherty silica, likely silicified volcanic particles), and minor feldspars (orthoclase, microcline) are closely packed, showing some secondary silicification and microstylolitic contacts. Kaolinite aggregates and goethite occur interstitially. Minor dolomite is porphyroblastic against the clastics. Heavy detrital minerals include coarse, angular tourmaline (O = dark green, E = colourless), purple and colourless zircon prisms and grains, colourless, step-etched garnet, and leucoxene.

Some 20 ft below the Poppingstone Sandstone in the River Irthing [6452 6960] is a hard, grey, sandy calcarenite (E 32958) containing appreciable amounts of mainly calcite (Plate XIII, fig. 3). Angular resistates (averaging 0·2 mm) comprise clear, igneous quartz, microcline and orthoclase, scattered amongst abundant, poorly sorted, calcarenitic granules, which are mainly randomly orientated. They include shell particles, arcuate tubules carrying pyrite crystals, brachiopods, foraminifera, bryozoa and crinoid stems. Black opaque streaks are probably of hydrocarbon. There are also fibres of organic phosphates.

A specimen (E 32959) of the Lampert Sandstone, collected at a waterfall [6470 6972] in the River Irthing, is a hard, even-grained (averaging 0·2 mm) subarkosic rock, composed of closely packed igneous and lesser metamorphic quartz showing much secondary silicification and the development of microstylolitic contacts, cherty silica, fine labile sericitic aggregates, particles of suspected volcanic derivation and conspicuous turbid orthoclase and fresher microcline. The sparse matrix includes a little muscovite, brownish granular authigenic anatase, zircon and minor carbonate. Thin, discontinuous veinlets are infilled with a soft mixture of kaolinite, illite and quartz, identified by an X-ray powder photograph (NEX 156).

The Spy Rigg Sandstone, sampled in the River Irthing [6520 7013], is pale buff-grey, even-grained (0·2 mm) and quartzitic (E 32961). The closely packed grains of igneous quartz and rock particles (cherty silica, quartzite) are partly aligned parallel to the bedding. Carbonaceous partings and ripple marks coated with fine muscovite are prominent. Heavy accessory minerals include subrounded to well-rounded colourless and purple zircon, well-rounded to angular tourmaline (O = dark olive green to black, E = very pale brown), dark reddish brown, well-rounded rutile, yellowish twinned [001] tablets of anatase, colourless, step-etched garnet, and much leucoxene.

A sandstone in the roof of the Appletree Limestone was collected from a small stream [6591 7051] on the south bank of the River Irthing. It is a fine-grained (0·1 mm), well-graded, fairly hard subarkosic sandstone (E 32962), with conspicuous fine mica on the bedding planes. Microstylolitic sutures and secondary silicification are prominent. Igneous quartz predominates, with metamorphic quartz, microcline, orthoclase and turbid polygranular quartz aggregates charged with microinclusions and perhaps of volcanic origin. Brownish euhedral clusters of authigenic anatase and rutile are also seen.

UPPER BORDER GROUP: NORTH-EASTERN AREA

A sandstone near the base of the group crops out in the Back Burn [6556 8506]. It is a calcitic fine-grained rock (E 33480) bearing casts of rootlets and moulds of worm-tubes and is even-grained (0·1 to 0·2 mm) with clastic grains of quartz, plagioclase, orthoclase, microcline and polygranular quartz strewn through a calcitic matrix. Calcarenitic particles are represented by dusty, microcrystalline calcite and distinguished from the cementing clear, coarse calcite, which has extensively replaced the resistate grains. Minor components include granules of pyrite, flakes of chlorite and grains of greenish tourmaline.

Two specimens (E 32782, 32783) collected from Blackcleugh Burn [6528 8238], are brecciated, dolomitized, carbonaceous and calcitic sandstones. Phenoclasts of allochthonous sandy organic carbonate and carbonate-cemented medium quartz-sandstone are somewhat rounded, and largely replaced by ferroan dolomite ($\omega = 1{\cdot}693$). Organic remains are surrounded by rims of ferroan dolomite, pale brown in section and exhibiting rhombic outlines, porphyroblastic against quartz grains. The organic fragments have apparently been marginally corroded, and extinguish simultaneously with their clearer, pale brown ferroan dolomite rims, showing complete replacement.

Four specimens were sectioned (E 32760–3) from a 25-ft face in a disused quarry [6495 7982] on Barren Crags. They are fairly well-graded (0·2 to 0·3 mm) closely packed medium sandstones composed of interlocking quartz, minor potash feldspars, oligoclase and rock particles. Secondary silicification occurs in places, though elsewhere the grains closely interlock. Intergranular spaces are occupied by illite, chlorite and kaolinite. Muscovite flakes are liberally scattered on bedding planes. Goethite impregnates one specimen (E 32760), extensively replacing the clastics and matrix alike. Heavy minerals concentrated from a second specimen (E 32762) included rounded, colourless zircon, a trace of rose-coloured zircon, angular prisms of tourmaline, (O = dark brown, E = colourless to pale pinkish brown; O = dark blue, E = colourless; O = dark green, E = colourless), dark brown and yellowish brown, angular rutile, yellow tablets of anatase, and a trace of deep blue-black sapphire.

Above the Low Cranecleugh Coal in Whickhope Burn [6612 8553] is a hard, porous, ferruginous sandstone (E 32948) consisting of interlocking or secondarily silicified medium (0·5 mm) grade igneous, and lesser metamorphic, quartz and rock particles—quartzite, chert and other polygranular quartz grains. Another sandstone (E 33479) lying at a higher horizon farther downstream [6665 8617] is fine-grained and quartzitic, bearing worm tubes. It consists of tightly packed, even-graded (0·15 mm) grains of mainly igneous quartz and polygranular quartz together with labile rock particles. There is much secondary silicification post-dating coatings of ferric oxide around quartz cores. Rather sparse matrix includes kaolinite aggregates partly recrystallized, and muscovite.

A dolomite siltstone (E 32946) taken in Whickhope Burn [6691 8618] about 6 ft below the base of the Bull Crag Sandstone is composed of a mosaic of even-grained (0·04 mm) rhombic dolomite ($\omega = 1{\cdot}684$) commonly charged with submicroscopic vermicular inclusions. Ferroan dolomite ($\omega = 1{\cdot}695$) is also present with a little hydrocarbon.

Two specimens (E 32944, 32945) of the Bull Crag Sandstone itself were obtained farther down the burn [6699 8615]. They are quartzitic, hard, secondarily silicified sandstones with carbonaceous partings and ferric oxide staining. Tightly packed quartz, quartzite, cherty silica and cloudy polygranular quartz particles show microstylolitic contacts. Matrix is sparse with a little chlorite. Heavy minerals from one specimen (E 32944) include rounded to sharply euhedral zircon; pale yellow tablets of anatase showing marked blue-purple interference colours; rounded to subangular tourmaline (O = dark green–dark brown, E = very pale brown), dark reddish or yellowish-brown prismatic rutile, angular apatite, and abundant opaque white leucoxene, which crystallographically consists (X-ray powder photograph NEX 174) of rutile. Goethite (NEX 175) impregnates the specimens.

Below the Merlin Crags Sandstone in Whickhope Burn is a pale grey to brown ferruginous sandstone 4 to 6 ft thick [6831 8642]. It is well-bedded and evenly grained (0·2 mm) with conspicuous carbon and muscovite flakes on bedding planes. Predominant quartz and polygranular quartz particles, with sparse microcline show moderate sphericity and roundness and are cemented and replaced by slightly ferroan dolomite ($\omega = 1{\cdot}696$). Secondary silica overgrowths on the quartz clearly antedate the carbonate cementation. There is a little intergranular kaolinite, muscovite and coarse chlorite. The grain-size of the carbonate approaches that of the clastic grains and there is some evidence to suggest that much quartz has been replaced with vestiges of quartz in optical continuity surrounded by replacive carbonate.

The Merlin Crags Sandstone, sampled in Whickhope Burn [6838 8645], is strongly current-bedded and well-graded (0·3 mm), with closely packed igneous, and lesser metamorphic, quartz, cherty silica and quartzite with some secondary silicification (E 32940). The matrix includes granular kaolinite and a little fine illite. Heavy minerals include prominent, yellow, tabular anatase, coarse, angular tourmaline (O = deep blue, E = colourless; O = dark brown, E = colourless–pink), angular apatite, rounded, purple and colourless zircon, deep reddish brown rutile, leucoxene, and a trace of sapphire.

The Grey's Crags Sandstone at Grey's Crags [6929 8666] is an irregularly bedded, pale buff, quartzitic sandstone, with dark carbonaceous and micaceous partings. In thin section (E 32943) closely packed, evenly graded (0·2 mm) quartz, cherty silica and quartzite grains show microstylolitic contacts. Secondary quartz overgrowths are common. Heavy minerals include rounded, colourless and purple zircon, subangular apatite, dark reddish brown subangular rutile, abundant yellowish brown tablets of anatase, subrounded tourmaline (O = dark green to black, E = pale brown) and opaque leucoxene.

LOWER LIDDESDALE GROUP

The only sandstone examined from the Lower Liddesdale Group occurs above the Denton Mill Limestone in Tipalt Burn [6836 6828]. In thin section (E 32964) it is seen to be fairly well graded (averaging 0·2 mm), with closely packed clastics (quartz, quartzite, conspicuous altered feldspars—perthite, microcline, orthoclase) showing some orientation parallel to the bedding. Microstylolitic contacts and secondary silica overgrowths around quartz cores are conspicuous. Illite, muscovite and kaolinite aggregates occur in the matrix and along bedding planes. Heavy minerals comprise subangular to rounded zircon; subangular, colourless, step-etched garnet, elongated yellowish brown, subangular rutile, angular to subangular and well-rounded tourmaline (O = dark blue, E = pale brown; O = black, E = pale brown; O = dark green, E = pale green; O = deep yellow, E = colourless), subangular apatite, authigenic brown anatase, and rare, dark blue sapphire.

UPPER LIDDESDALE GROUP

Three specimens of sandstones were examined from the Penton anticline (p. 161) exposed in the banks and stream bed of the Liddel Water at Penton Bridge [432 774].

The lower part of the Bridge Sandstone (p. 291) (E 32933: Pl. XIII, fig. 4) is pale grey (part iron-stained), fine-grained, micaceous, strongly current bedded and subarkosic. Even grading (median granularity 0·15 to 0·2 mm), tight packing with microstylolitic contacts and some secondary silicification are characteristic. Igneous, and lesser metamorphic, quartz predominates with conspicuous potash feldspars (orthoclase microcline), minor rock particles (quartzite, cherty silica) and sparse heavy minerals (Fig. 31). Granular kaolinite, transgressive muscovite, and iron-stained illite occur interstitially together with black, opaque microbotryoidal grains which are amorphous (X-ray photograph NEX 148). This material is most probably a pyrobitumen and is associated with micas on bedding planes. A further indication of weak mineralization is provided by interstitial baryte. Accessory heavy minerals include well-rounded to subrounded, colourless and purple zircon grains and prisms, well-rounded and prismatic tourmaline (O = dark olive green to brown, dark brown or dark green, E = colourless), dark reddish brown and yellowish brown subangular rutile, rare brown anatase, sparse colourless garnet, subangular ilmenite, and a trace of sapphire. A specimen (E 32930) from the upper part of the Bridge Sandstone is texturally and mineralogically similar except that the baryte and hydrocarbon mineralization was not detected. Pellicles of finely divided clay minerals and ferric oxide occur around the quartz cores and predate secondary overgrowths. Amongst the polygranular quartz particles occur brownish grains of extrusive igneous appearance.

A flaggy, very micaceous sandstone (E 32932), occurring between the Penton and Bridge limestones in the southern limb of the anticline, differs from the above sandstones in being calcitic and finer grained (median granularity 0·08 mm). The clastic materials are, however, subarkosic and show varying stages of marginal replacement by the calcite matrix.

The sandstone below the Greenhead Bankhouses Limestone was sampled on the left bank of Tipalt Burn in a small streamlet [6805 6790]. It is a well-graded (median granularity 0·1 mm), closely packed, fine sandstone (quartz, orthoclase, perthite, microcline, cherty silica, quartzite) with a little fine muscovite and illite on bedding planes, and shows some secondary silicification around quartz cores and microstylolitic contacts (E 32965).

A higher sandstone forming a waterfall [6676 6735] in Tipalt Burn is coarser (0·3 mm) than the previous specimen, though with conspicuous feldspars and labile rock particles, indicating a subgreywacke trend. The texture is similarly even-grained, with sparse illite, muscovite and kaolinite in the matrix. The clastics are commonly interlocking with microstylolitic contacts in places (E 32966).

The sandstone below the Greenhead Tynebottom Limestone in the Tipalt Burn [6637 6683] contains tightly packed, even graded clastic quartz (fine sand grade—0·09 mm), showing interlocking, microstylolitic contacts and secondary silicification (E 32969). Rather turbid and altered potash feldspars are conspicuous, with minor cherty silica. The matrix includes muscovite, much ferric oxide and a trace of glauconite. Heavy minerals include subangular to subrounded, colourless zircon, dark yellowish and reddish brown rutile, angular to subrounded tourmaline (O = dark greenish black, E = pale pink; O = dark olive green, indigo blue, E = colourless), and clusters of very small dark yellowish brown authigenic anatase.

The sandstone above the Greengate Well Limestone, forming a waterfall exposure [6636 6696] in Tipalt Burn, has flaggy partings coated with fine white mica and carbon. Clastics (quartz, quartzite) are very tightly packed and evenly graded (0·08 mm) with secondary silicification and microstylolitic contacts (E 32967). Heavy minerals include subrounded, colourless and purple zircon, subangular to subrounded tourmaline (O = dark olive green, E = colourless; O = black, E = pale pink; O = deep blue, E = colourless), subangular reddish brown rutile, and squat brownish bipyramids of anatase. Carbonate (mainly ferroan dolomite with $\omega = 1{\cdot}694$) replaces the clastics. Fine micas (muscovite, hydrobiotite, chlorite, illite) are conspicuous along bedding planes. This sandstone is stratigraphically equivalent (p. 161) to that (E 32932) overlying the Penton Limestone and comparison shows close lithological similarities of texture, flaggy nature and abundant micas, though the carbonates appear to differ and feldspars were not detected in the present specimen. R.K.H.

REFERENCES

FOWLER, A. 1966. The stratigraphy of the North Tyne basin around Kielder and Falstone, Northumberland. *Bull. geol. Surv. Gt Br.*, No. 24, 57–104.

GARWOOD, E. J. 1931. The Tuedian beds of northern Cumberland and Roxburghshire east of the Liddel Water. *Q. Jl geol. Soc. Lond.*, **87**, 97–159.

GILLIGAN, A. 1920. The petrography of the Millstone Grit of Yorkshire. *Q. Jl geol. Soc. Lond.* **74**, 251–94.

KRYNINE, P. D. 1946. The tourmaline group in sediments. *J. Geol.*, **54**, 65–87.

LUMSDEN, G. I. and WILSON, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

RAYNER, D. H. 1953. The Lower Carboniferous rocks in the north of England: A review. *Proc. Yorks. geol. Soc.*, **28**, 231–315.

ROBSON, D. A. 1956. A sedimentary study of the Fell Sandstones of the Coquet valley, Northumberland. *Q. Jl geol. Soc. Lond.*, **112**, 241–62.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

Chapter IX

MILLSTONE GRIT SERIES

GENERAL ACCOUNT

TO CONFORM WITH Geological Survey practice in other parts of England and Wales the Millstone Grit Series in Northern England is now equated with the Namurian and is defined as extending from the lowest occurrence of *Cravenoceras leion* up to the base of a marine band containing *Gastrioceras subcrenatum*. Enough evidence has accumulated to show that through the North of England the lower limit can be drawn most conveniently at the base of the Great Limestone (Johnson and others 1962). The local equivalent of this limestone was recognized at outcrop in the Liddel Water by Price (1953, p. 31) and named Catsbit Limestone by Lumsden and Wilson (1961, p. 8). It is overlain in the Liddel Water by about 155 ft of cyclic deposits including the Blae Pot Limestone and several seams known collectively as the Penton Coals (Fig. 32).

These beds, which comprise only the lowest part of the Millstone Grit Series, are restricted in outcrop to a small area bounded to north and south by the Penton Linns and Archerbeck faults respectively, and to the east by the Hilltop Fault. Presumably, however, beds forming the upper part of the series are present at depth beneath Coal Measures farther south-west in a narrow belt between the Liddel Water and the Hilltop Fault. Although they have not been proved by boring, it may be inferred from a comparison of relevant sections in neighbouring ground with the sequences in Northumberland and Durham (Fig. 32) that within this belt the Millstone Grit Series as a whole is likely to be about 1100 ft thick and to include some representative of all the goniatite stages established by Bisat (1924, 1928) and others in the Central Pennines.

As thus defined the Millstone Grit Series includes the whole of the 'Upper Limestone Group' and parts of the 'Millstone Grit' of older classifications in Northumberland and Durham: it is also equivalent to the whole of the 'Limestone Coal Group', 'Upper Limestone Group', and parts of the 'Lower Limestone Group' and 'Millstone Grit' of Barrett and Richey (1945).

Previous authors (Peach and Horne 1903; Barrett and Richey 1945) equated the Penton Coals with the Kilnholm Coals, but from their position relative to the Catsbit (Great) Limestone they are more correctly correlated with the Oakwood Coals of Northumberland. Although correlation of individual seams is difficult it seems probable that the Lower Coal and limestone overlying it are probably the equivalents of the Oakwood Coal and Lower Oakwood Limestone of Brampton (Trotter and Hollingworth 1932, pl. iii).

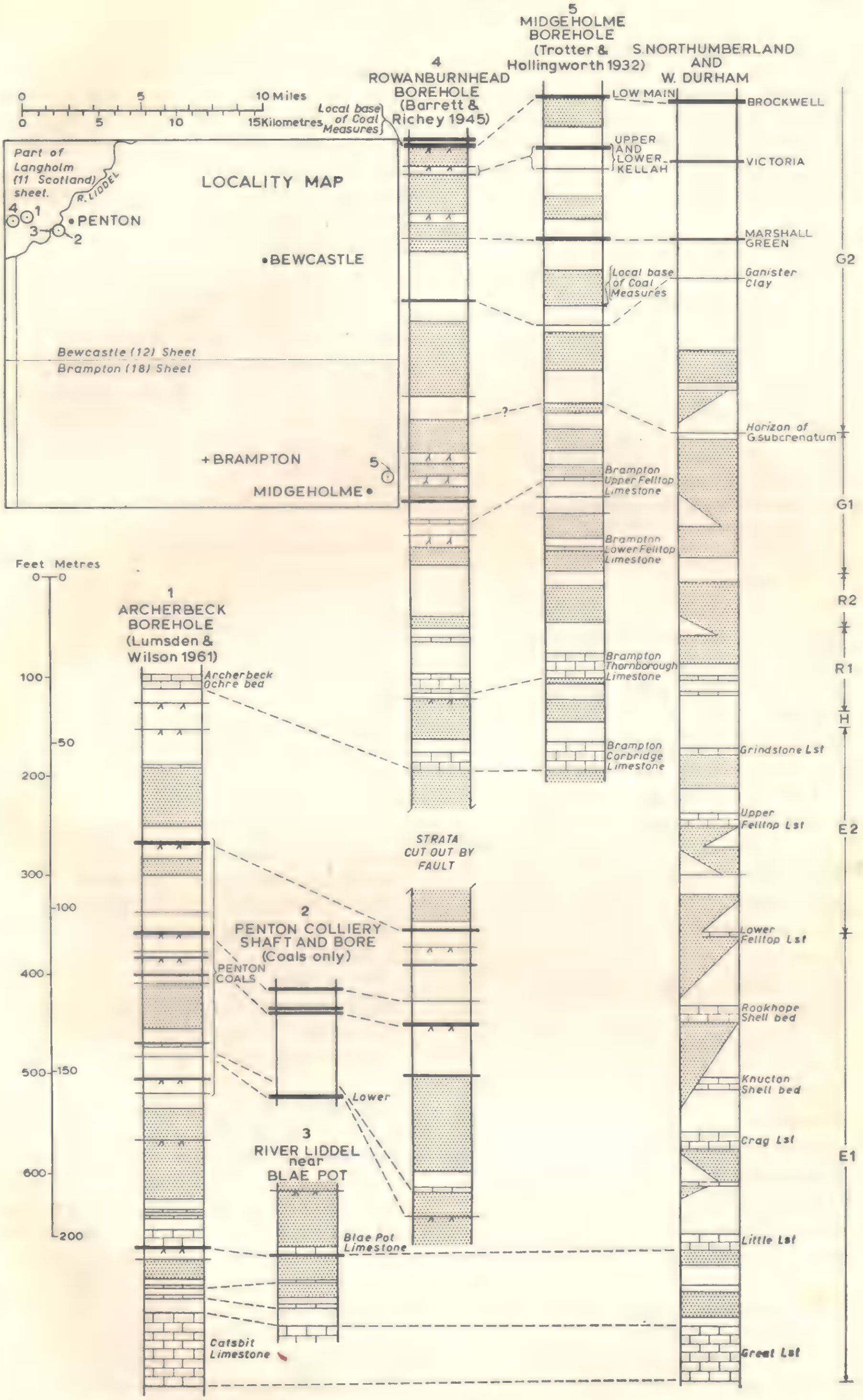


FIG. 32. *Comparative vertical sections of the Millstone Grit Series and part of the Lower Coal Measures. For key see Fig. 5*

DETAILS

The upper part of the Catsbit Limestone and about 155 ft of overlying strata are exposed in the Liddel Water south-west of Penton Mill House, between the Penton Linns Fault [4305 7736] and Archerbeck Fault [4311 7700]:

	ft
Sandstone, grey medium grained; flaggy at base	6
Coal and carbonaceous shale [Cliff 4315 7702]	¼
Sandstone, light grey rooty ..	3
Sandstone, massive current-bedded	12
Sandy shale, grey nodular (*inaccessible*)	6
Sandstone, flaggy; passing upwards into massive sandstone	18
Sandstone, shaly finely-flaggy; rare pyrite nodules	7
Sandstone, fossiliferous calcareous; shaly partings	1½
Sandstone, fossiliferous calcareous	1¼
Sandstone, dark grey rubbly; rare brachiopods	1¾
Sandstone, dark grey calcareous micaceous	1
Sandstone, dark grey shaly ..	4
BLAE POT LIMESTONE	
Limestone, hard grey crystalline bedded; brachiopods and corals [4310 7707]	10
Coal (*beneath water level*) ..	1
Sandstone	10
Not exposed	10
Limestone	2
Sandstone, massive medium-grained	14
Sandstone, flaggy; merging downwards into sandy shale	7
Shale, sandy	1
Limestone	1
Sandstone, flaggy	2½
Limestone	1
Alternations of sandstone and shale	5
Shale, dark grey; ironstone nodules, hard, calcareous and fossiliferous near the base	12
CATSBIT LIMESTONE	
Limestone, hard crinoidal, rare shaly partings, hematitic specks, much shattered and veined near fault	12

The coal beneath the Blae Pot Limestone appears to be of poor quality. The Blae Pot Limestone and immediately overlying beds are accessible only on the right (Scottish) bank, but the remainder of the section can be seen (and reached with difficulty) in the left bank of the miniature gorge formed by the thick sandstones.

A strike section through the uppermost 37½ ft of the Catsbit Limstone is exposed, terminated to the west by a fault, in the left bank of the Liddel Water east of Penton Bridge, at Shankend [4365 7728]. The beds dip a little to the east of north at 35°, and although the lithology varies slightly along the strike, the following section may be taken as representative:

	ft
Limestone, blue; brachiopods ..	3
Shale, grey calcareous	1¼
Limestone, blue fine-grained crystalline; brachiopods	2½
Shale, blue calcareous; productids	½
Limestone, blue fossiliferous; brachiopods	5
Shale, blue calcareous; large productids and corals	¾
Limestone, blue-grey; brachiopods	1¾
Shale, blue-grey calcareous ..	½
Limestone, blue crystalline; productids	¾
Shale, blue-grey calcareous; limestone nodules; large productids and *Spirifer sp.* at base	4¾
Limestone, blue fine-grained; thin shaly partings; productids ..	2¼
Shale, grey fossiliferous calcareous	3
Limestone, creamy-grey knotty massive crinoidal	12

Beds above the Catsbit Limestone up to and including the Blae Pot Limestone are poorly exposed in the river as far north as the Penton Linns Fault. The Blae Pot Limestone is also exposed on the southern side of the fault 150 yd S.E. of Penton Bridge. In the Archerbeck Bore the lowest of the Penton Coals is 137 ft above the top of the Blae Pot Limestone (Lumsden and Wilson 1961, p. 21). Three, or doubtfully four, of the coals were noted at Penton Colliery, from the shaft of which the following section has been recorded (Smith 1912, pp. 156–7):

		ft
UPPER COAL		
Coal		2¼
Strata		15
MIDDLE COAL		
Coal 20 in		1⅔
Black stone		1⅔
Coal 22 in		1¾
Strata		84
LOWER COAL		
Coal 18 in		1½
Stone		⅔
Coal 6 in		½

The Lower Coal is exposed in the right bank of Liddel Water [4349 7730], where it is 2 ft 5 in thick and is overlain, a few feet higher in the sequence, by a thin limestone. The Middle and Upper coals are also exposed in the right bank [4356 7730] where the section is

		ft
UPPER COAL		
Coal		1¾
Fireclay	about	3
Coal		¼
Shale; *Lingula*	about	15
MIDDLE COAL		
Coal		⅓
Fireclay		2¼
Coal, at least 26 in		2¼

Faulted sections through the coals and associated sandstones and seatearths can be seen in the railway cutting N.W. of Penton House on both sides of the road bridge. The Lower Coal is partially exposed over a thickness of 1 ft [4336 7702].

A small area of Millstone Grit has been mapped on structural grounds beneath drift south-east of Watleyhirst. J.B.W.D.

REFERENCES

BARRETT, B. H. and RICHEY, J. E. 1945. Economic geology of the Canonbie Coalfield *Wartime Pamph. geol. Surv. Gt Br.*, No. 42.

BISAT, W. S. 1924. The Carboniferous goniatites of the north of England and their zones. *Proc. Yorks. geol. Soc.*, **20**, 40–124.

—— 1928. The Carboniferous goniatites of England and their continental equivalents. *C. r. Congr. Avanc. Étud. Stratigr. Géol. carbonif.* 1927, 117–33.

JOHNSON, G. A. L., HODGE, B. L. and FAIRBURN, R. A. 1962. The base of the Namurian and of the Millstone Grit in north-eastern England. *Proc. Yorks. geol. Soc.*, **33**, 341–62.

LUMSDEN, G. I. and WILSON, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

PEACH, B. N. and HORNE, J. 1903. The Canonbie Coalfield: its geological structure and relations to the Carboniferous rocks of the north of England and central Scotland. *Trans. R. Soc. Edinb.*, **40**, 835–77.

PRICE, R. H. 1953. In *Summ. Prog. geol. Surv. Gt Br.*, for 1952, 31–2.

SMITH, S. 1912. *Report of the committee appointed to report upon the Carboniferous Limestone formation of the north of England, with special reference to its coal resources.* Newcastle upon Tyne.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

Chapter X

COAL MEASURES

GENERAL ACCOUNT

REDDENED ROCKS of Upper Coal Measures age crop out along a narrow belt of country bounded on its longer sides by the Liddel Water and the Hilltop Fault. Northwards these rocks are terminated by the Archerbeck Fault, and towards the south-west they continue for an unknown distance beneath an unconformable cover of Permo-Triassic strata.

The principal exposures are in the Liddel Water and its minor tributaries; they consist mainly of red sandstones and sandy shales with rare thin bands of *Spirorbis* limestone. Coal is present only at a locality adjacent to the Archerbeck Fault where the measures are grey and include a single thin seam.

In the first published geological account of the Canonbie district, Gibsone (1861) assumed the red measures to be Permian, but Binney (1863) recognized *Spirorbis* in the limestones and realized that some part of the succession was probably Upper Coal Measures in age. They were nevertheless mapped as 'Carboniferous Limestone Series' by the surveyors of the primary one-inch geological maps. Subsequently, Kidston (1893, 1903) identified plants obtained from 'Jockie's Sike' (now known as Baxton Gill) as of undoubted Upper Coal Measures (Radstockian) age, and the beds were so designated by Peach and Horne (1903). Still later the plant evidence was confirmed by the discovery of non-marine bivalves of the zone of *Anthraconauta tenuis* from the same localities in 'Jockie's Sike' (Barrett and Richey 1945).

Trotter (1953, pp. 14–5) has suggested that most of the reddening can be related to a process of secondary oxidation of originally grey rhythmically deposited Coal Measures. He believes, however, that the topmost 400 ft of measures may be primary red beds: they include the exposures in the Liddel Water.

On the English side of the river two borings—namely Riddings (1914) and No. 2 Inch (1860)—have penetrated the red measures (Barrett and Richey 1945, fig. 8), but the full thickness is not proved nor is anything known of the grey Coal Measures which are presumed to underlie them. On the Scottish side, however, the red measures are said (op. cit., p. 8) to be at least 1520 ft thick underlain by more than 1000 ft of grey 'Productive' Coal Measures. The latter include the marine band which occurs in the non-marine bivalve zone of *Anthraconaia modiolaris*, and which is used throughout the country as a boundary between Lower and Middle Coal Measures: they also include six marine bands lying within the zone of *Anthracosia similis—Anthraconaia pulchra* (Lumsden 1956, p. 45). A full account of these measures will be found in the memoir (Lumsden and others 1967) accompanying the Langholm (11) Sheet of the one-inch geological map of Scotland.

DETAILS

Upper Coal Measures are exposed discontinuously in the left bank of the Liddel Water between the western margin of the district and the Archerbeck Fault [4310 7700]. They consist mainly of purple micaceous sandstones alternating with thinner bands of red sandy shales and variegated marls. Greenish patches in the marls seem to be associated with carbonaceous material, but only one coal is present.

West of Crookholm Farm [426 764] the prevailing dip is easterly, but east of the farm the beds are either horizontal or dip gently to the south-west. In Jockie's Sike (Baxton Gill) the dip, although variable, is predominantly a little to the south of west, whilst in the railway cutting immediately south of the Archerbeck Fault it is due west at about 45°. Several unmapped faults may be present.

The following beds dipping at 10° to north-east were measured in the Liddel Water at the railway viaduct [4106 7553];

	ft
Shale, purple micaceous sandy ..	4
Sandstone, shaly micaceous ..	1
Shale, purple micaceous sandy ..	5
Sandstone, purple shaly ..	5

Half a mile upstream, 15 ft of flaggy, micaceous purple sandstone are seen dipping at 2° to south-east into the left bank of the river. On the same bank, ¼ mile to N.E. [4190 7631], 11 ft of similar sandstone dip eastward at 6°. Still farther upstream [4234 7622: loc. 33 of Barrett and Richey 1945, p. 36 and fig. 5] this eastward dip decreases to 2° in 8 ft of red shales with thin lenses of red and green limestone. The shales contain *Spirorbis sp.*, *Anthraconauta phillipsii* (Williamson), *A.* aff. *tenuis* (Davies and Trueman), *Carbonita salteriana* (Jones) and *Geisina sp.*

The following section [4252 7619: loc. 34 of Barrett and Richey op. cit.] is seen 230 yd S.S.W. of Crookholm Farm:

	ft
Sandstone, red-purple micaceous	4
Shale, red, finely laminated; irregular lumps of green and red limestone	12
Sandstone, purple	2
Shale, red; *Spirorbis sp.* and lumps of limestone	2

The shales contain a fauna similar to that listed above in addition to *A.* cf. *wrighti* (Dix and Trueman) and *Carbonita* cf. *wardiana* (Jones and Kirkby).

Similar strata are exposed on the same bank for a distance of 130 yd upstream, but the shale bands (locs. 35–7 of Barrett and Richey, (op. cit.) contain only *A. phillipsii*, *A. tenuis* and *A.* cf. *wrighti*, with plant and fish remains.

Mr. Calver remarks that all these Liddel Water faunas are referable to the *A. tenuis* Zone. He attaches some importance to the presence of the ostracod *Geisina* in the two downstream localities (locs. 33 and 34), for this fossil is rarely found in the Upper Coal Measures except at the extreme base. The only other localities from which it is known also occur in the Canonbie coalfield, namely Archer Beck and the River Esk, and there is strong faunal evidence for linking these bands with those in the Liddel Water (Trueman *in* Barrett and Richey, pp. 38–9).

Along the ¼-mile stretch of Jockie's Sike (Baxton Gill) which extends south-eastward from the railway embankment [4219 7516], red and purple sandstones alternate with red micaceous sandy shales and red marls lithologically similar to the beds in the Liddel Water. Kidston (1893) and Crookall (*in* Barrett and Richey 1945, pp. 41–2) assigned plants obtained from these shales to the Radstockian. Non-marine fossils collected along the sike (locs. 39–41 of Barrett and Richey 1945, pp. 38–9 and fig. 5) include *Anthraconauta phillipsii*, *A. tenuis*, *Anomalonema* [*Estheriella*] *defretinae* Novojilov, *Carbonita salteriana*, *C. pungens* (Jones and Kirkby), *Mylacris similis* Handlirsch and *Palaeoxyris sp.* A specimen of *A. tenuis* from the sike was figured by Weir (1960, pl. xxxii, fig. 25), and the insect wing, *M. similis*, was figured by Wallis (1945, pl. iii).

According to Mr. Calver the fauna from the sike contains typical *Anthraconauta tenuis* and is therefore placed definitely in that zone. There is no suggestion of either the underlying *A. phillipsii* Zone or the overlying *Anthraconaia prolifera* Zone. The *Anomalonema* [*E.*] *defretinae* is also a characteristic fossil of the *A. tenuis* Zone.

Plants are also common at these localities and the species obtained have been summarized by Crookall (*ibid.*, p. 42). The composite list is as follows: aff. *Alethopteris davreuxi* (Brongniart), *A. grandini* (Brongniart), *A. serli* (Brongniart), *Annularia*

stellata (Schlotheim), *Asolanus camptotaenia* Wood, *Asterophyllites equisetiformis* (Schlotheim), *Asterotheca oreopteridia* (Schlotheim), *Calamites carinatus* Sternberg, *C. undulatus* Sternberg, *Lepidodendron lanceolatum* Lesquereux, *Neuropteris flexuosa* Sternberg, *N. ovata* Hoffmann, *N. rarinervis* Bunbury, *N. scheuchzeri* Hoffmann, cf. *Ptychocarpus hexastichus* Weiss, ?*Sphenophyllum majus* Bronn and *Trigonocarpus sp.* Crookall notes that the occurrence of 'several examples of *Neuropteris ovata*, many of *N. scheuchzeri* and a few of Pecopterids suggests an horizon low down in the Radstockian Stage', which equates with the *A. tenuis* Zone.

Red sandstones and marls similar to the beds in Baxton Gill are also exposed in three nearby parallel streamlets [419 756, 421 756 and 426 759].

The following section is exposed in the east side of the railway cutting [4336 7698] 80 yd W. of Penton House:

	ft
Grit, light grey feldspathic ..	1
Shale, blue-grey	½
Fireclay, dark grey	1¼
Coal	¾
Shale, dark grey rooty	1
Fireclay, grey	⅔
Shale, black sandy rooty	10
Sandstone, greenish white gritty; reddened at top and bottom ..	7½
Shale, blue-grey rooty	2
Sandstone, grey rooty; shaly at base	2¾
Sandstone, grey flaggy rooty ..	¼
Not exposed	3
Sandstone, white to greenish white, fine- to medium-grained; bands of coarse, friable current-bedded grit	35

Reddening is vestigial and suggests that these beds are lower in the succession than the strata exposed in the river. This would accord with the westerly dip in the cutting, though the steep angle (44°) is probably attributable to the Archerbeck Fault which lies immediately to the north. J.B.W.D.

REFERENCES

BARRETT, B. H. and RICHEY, J. E. 1945. Economic geology of the Canonbie Coalfield. *Wartime Pamph. geol. Surv. Gt Br.*, No. 42.

BINNEY, E. W. 1863. Further observations on the Carboniferous, Permian and Triassic strata of Cumberland and Dumfries. *Mem. Lit. and Phil. Soc. Manchester*, 2, 3rd Series, 343–88.

GIBSONE, E. 1861–2. A geological paper on the border districts of Dumfriesshire, Cumberland and part of Roxburghshire, including the coal formation of Canonbie, etc. *Trans. N. Engl. Inst. Min. mech, Engrs.*, **11**, 65–88.

KIDSTON, R. 1893. On the various divisions of British Carboniferous rocks, as determined by their fossil flora. *Proc. Roy. Phy. Soc. Edin.*, **12**, 183–257.

—— 1903. The fossil plants of the Carboniferous rocks of Canonbie, Dumfriesshire and of parts of Cumberland and Northumberland. *Trans. R. Soc. Edinb.*, **40**, 741–833.

LUMSDEN, G. I. 1956. In *Summ. Prog. geol. Surv. Gt Br.* for 1955.

—— TULLOCH, W., HOWELLS, M. F. and DAVIES, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

PEACH, B. N. and HORNE, J. 1903. The Canonbie Coalfield: its geological structure and relations to the Carboniferous rocks of the north of England and central Scotland. *Trans. R. Soc. Edinb.*, **40**, 835–77.

TROTTER, F. M. 1953. Reddened beds of Carboniferous age in north-west England and their origin. *Proc. Yorks. geol. Soc.*, **29**, 1–20.

Chapter XI

PERMO-TRIASSIC ROCKS

GENERAL ACCOUNT

THE PERMO-TRIASSIC SEDIMENTS were deposited unconformably on an eroded surface of folded and faulted Carboniferous rocks. Their outcrop within the Bewcastle district is restricted to a triangular tract of about 8 square miles in the south-west and to a smaller tract of about 1 square mile, bounded on two sides by faults, near Kirkcambeck village.

These tracts form part of the northern fringe of the Solway Basin, which is covered mainly by the Longtown (11), Carlisle (17) and Brampton (18) sheets of the One-inch Geological Map of England and Wales. In order to complete the description of the Permo-Triassic rocks of the basin, the survey of those sheets in 1921–3 was extended to include the two tracts in the Bewcastle district, and the details given in a subsequent part of this chapter are reproduced from the sheet memoirs by Dixon and others (1926) and Trotter and Hollingworth (1932).

The generalized succession of the Permo-Triassic rocks of the Solway Basin and the Vale of Eden, given in the following table, is based on the work of Trotter and Hollingworth (op. cit., p. 124) and Meyer (1965); the correlation with S.E. Durham is based partly on the faunal evidence adduced by D. B. Smith (in discussion of Meyer 1965).

PERMO-TRIASSIC SUCCESSION

Solway and the Vale of Eden	Maximum thickness in feet	South-east Durham
Stanwix Shales	900	Keuper Marl
Kirklinton Sandstone St. Bees Sandstone	3200	Bunter Sandstone
St. Bees Shales, with gypsum-anhydrite beds Hilton Plant Beds	420 100	Upper Permian Marls Upper Magnesian Limestone Middle Permian Marls Lower Magnesian Limestone Marl Slate
Penrith Sandstone and Brockram	1500	Basal Permian Sands and Breccias

The lower members of this sequence are overlapped northwards through the Vale of Eden so that in the Bewcastle district the St. Bees Shales, with local basal conglomerate, rest directly on Carboniferous. Because of subsequent erosion the highest member, the Stanwix Shales, is also missing from the district.

Basal Conglomerate. In the Riddings Bore, just beyond the western margin of the district, the basal conglomerate is recorded as being 1¼ ft thick. Traced to the east and south-east it increases in thickness, being 6 ft in Carwinley Burn and up to 30 ft in the Cam Beck at Kirkcambeck and in Hether Burn at Hethersgill. It is a hard, dull red or purplish rock formed of ill-sorted, commonly platy fragments of Carboniferous sandstone and limestone aligned approximately parallel to the bedding. The limestone fragments range in colour from grey through pink to deep red, the last being in the majority. Most of the sandstone fragments are dull purple and the matrix consists mainly of pink, locally calcareous sand.

St. Bees Shales. The sequence of St. Bees Shales exposed in the River Lyne is faulted, but it appears to exceed 180 ft in thickness. About 200 ft of these measures are exposed in Carwinley Burn and 180 ft in Cam Beck. They consist of dull red and reddish brown shales with sandy bands. The beds become increasingly sandy upwards and there is a passage into the overlying St. Bees Sandstone.

Near Cocklakes, about 10 miles south of the district, gypsum and anhydrite occur in the lower part of the shales and have been worked. These deposits are also recorded at a depth of 82½ ft in the Riddings Bore (Dixon and others 1926, p. 98), but there is no published information on their possible extension into the district described here (see also p. 266).

St. Bees Sandstone is a dull red, compact, micaceous rock which has been quarried for building stone. It is said to include subordinate beds of shale (Trotter and Hollingworth 1932, p. 137). The sand grains are mostly angular, rarely rounded; beds are generally evenly stratified, but are locally false-bedded. Ripple-marks and rain-pits suggest a shallow-water origin. The formation thickens towards the south-east from 500 ft in the Carwinley Burn (partly in the Longtown district) to about 1400 ft in the Hether Burn just beyond the southern edge of the Bewcastle district. The upper boundary with the Kirklinton Sandstone is ill-defined (Dixon and others 1926, p. 23) and about 250 ft of passage beds are said to intervene (Trotter and Hollingworth 1932, pp. 141–2).

The Kirklinton Sandstone occupies a small area, mostly under drift, in the extreme south-west corner of the district. There are few exposures and no continuous section. Lithologically it resembles the St. Bees Sandstone, but is said to be brighter red, highly false-bedded, and devoid of shale bands (Trotter and Hollingworth 1932, p. 141).

DETAILS

Carwinley Burn (Dixon and others 1926, p. 22). 'In Carwinley Burn, a tributary of the Esk which joins that river 2½ miles north-north-east of Longtown, the junction of the St. Bees Shales with the underlying Carboniferous is seen 600 yd east of the Longtown–Penton road (which crosses the burn just within Sheet 12). Here, 6 ft of coarse breccia dipping west-south-west at 10°, overlie purple shale and coarse flaggy sandstone dipping north-north-east at 50°. The chief constituents of the breccia are fragments of Carboniferous sandstone and limestone set in a matrix of coarse grit. Both fragments and matrix have been heavily impregnated by ferruginous solutions. The shales, which do not exceed 100 ft in thickness, pass laterally into sandy marls and argillaceous sandstones. In upward succession bands of sandstone of increasing thickness make their appearance, hence the St. Bees Shales pass gradually and imperceptibly into the sandstone above. At Riddings a borehole passed through about 100 ft of red marls with bands of gypsum. A breccia forms the base and conglomerates occur at two higher horizons in the sequence.'

River Lyne (Trotter and Hollingworth 1932, pp. 140, 142). 'A continuous but in places inaccessible section is furnished by the deep gorge of the River Lyne from Broomhills to the faulted junction with the Carboniferous exposed south of Brackenhill Tower. Near the onset of the Kirklinton Sandstone the two types of sandstone—St. Bees and Kirklinton—are occasionally interbedded. The dip varies considerably both in direction and amount. For a mile to the north-east of the Kirklinton Sandstone junction it is 10° to 12° to the south-west, decreasing to horizontal 600 yd south-west of Brackenhill Tower; near the faulted junction with the Carboniferous the dip is due west at a gentle angle.

Some 250 ft of passage beds are displayed in the River Lyne a mile north-eastward from Broomhills. The beds dip to the south-west and show the soft bright red Kirklinton type of sandstone alternating with the harder dull red micaceous sandstone considered typical of the St. Bees formation.'

Cam Beck (Trotter and Hollingworth 1932, p. 136). '300 yd north-west of Kirkcambeck church a coarse basal breccia appears in the bed and the banks of the Cam Beck, where it forms massive posts totalling at least 30 ft in thickness. The overlying shales and marls with occasional sandstones dipping gently to the south are poorly exposed in the Cam Beck at the southern end of the village.'

REFERENCES

DIXON, E. E. L., MADEN, J., TROTTER, F. M., HOLLINGWORTH, S. E. and TONKS, L. H. 1926. The geology of the Carlisle, Longtown and Silloth district. *Mem. geol. Surv. Gt Br.*

MEYER, H. O. A. 1965. Revision of the stratigraphy of the Permian evaporites and associated strata in north-western England. *Proc. Yorks. geol. Soc.*, **35**, 71–87.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

Chapter XII

STRUCTURE

General Account

The effects of three deformational episodes can be discerned within the Carboniferous and later rocks of the Bewcastle district. Two occurred during the post-Carboniferous pre-Triassic phase of the Hercynian orogeny and the third was probably Tertiary. There is also evidence of intra-Carboniferous differential downwarping associated with the accumulation of sediment in the depositional trough; the Carboniferous nevertheless forms a conformable sequence from the lowest Lynebank Beds certainly well into the Millstone Grit Series.

Some of the earliest effects of differential downwarping are apparent in the ground lying between the Antonstown and Harrett's Linn faults (Fig. 33) where the Upper Border Group is believed to be about 7000 ft thick as compared with 2000 ft to the south and 4000 ft to the north. It is presumed, therefore, that these faults approximately follow Lower Carboniferous hinge-lines.

The stresses set up during the two post-Carboniferous, pre-Tertiary orogenic phases were disposed in directions normal to each other. The earlier phase was one of south–north compression which gave rise in the eastern half of the area to gentle folding of moderate amplitude along east–west axes; it is thought that the Bewcastle Anticline originated at this time as a broad dome with a predominantly east–west trend. It is possible that this compression was followed by tension which initiated movement along some of the major east-north-easterly faults.

There followed the second deformational phase marked by a period of intense folding in which the direction of pressure was aligned approximately east–west. Because of deflections by the Caledonoid Southern Uplands Massif to the north these folds have north-north-easterly axes. The most prominent of these folds—the asymmetric Bewcastle Anticline—was superimposed on the earlier broad dome and overthrust to the west. The thrusting was accompanied by small scale, approximately east–west tear faulting normal to, and east of, the main thrust-plane. There was also lateral wrenching along at least one of the earlier east-north-easterly faults. Most of the north-north-easterly faults associated with this second phase, however, appear to be normal tension fractures; they probably followed the main period of compression because they appear to displace at least one of the east–west faults along which lateral movement is thought to have taken place.

In the third orogenic phase the Permo-Triassic rocks were gently tilted to the south-west and faulted. Several of the faults represent renewed movement along pre-existing Hercynian fractures. It is assumed that the age of these movements is, as in the Carlisle area nearby, post-Liassic and may possibly be Tertiary.

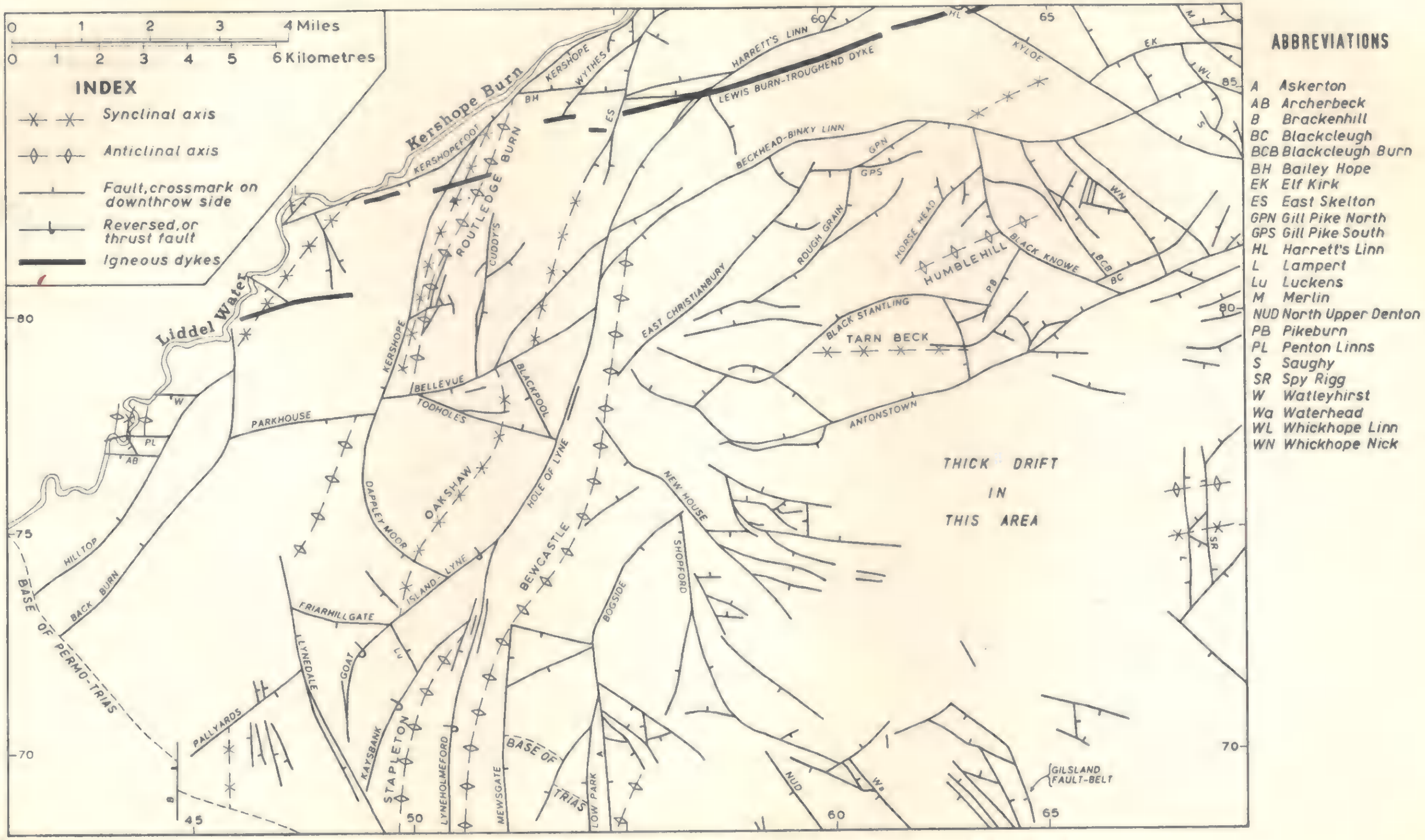


FIG. 33. *Sketch-map showing the main structural elements of the district*

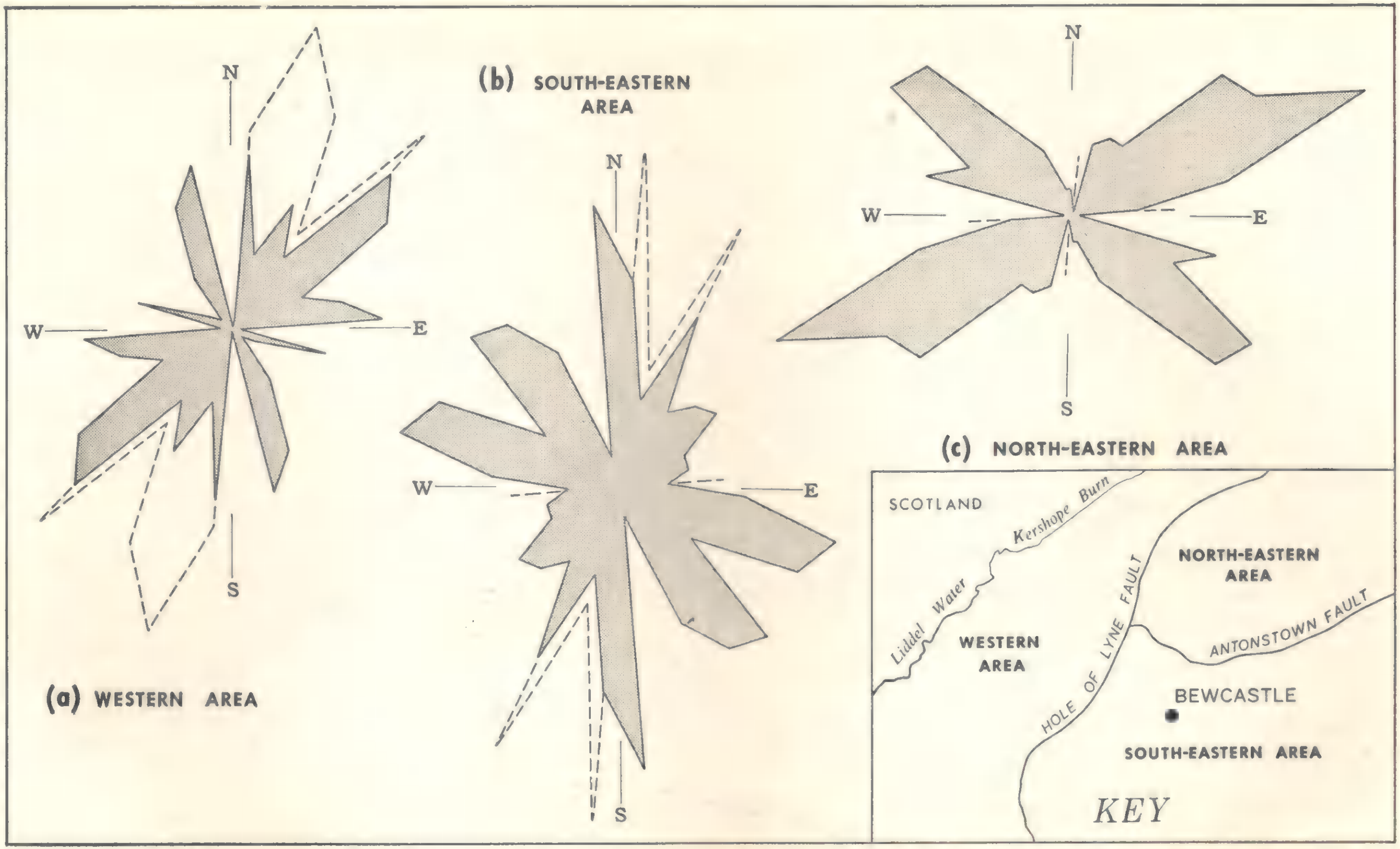


FIG. 34. *Rose diagrams to illustrate structural trends in different parts of the district. Each half-mile of fault or fold axis is represented by a unit length to the nearest 10° of arc from the centre of the rose. Faults are represented by shaded areas enclosed by solid lines, fold axes are shown as unshaded areas enclosed by broken lines. All faults are equally weighted regardless of their nature or amount of throw*

Structural Analysis. For the purpose of describing the structure, the district has been divided into three areas. They are defined in Fig. 34 which also shows rose diagrams for each area. As the areas are small and their boundaries arbitrarily chosen the indications of structural trend given by the rose diagrams must be regarded with caution. Nevertheless, the patterns serve to suggest differences as well as similarities between areas.

In the Western Area (a) north-north-easterly and north-easterly structures are clearly dominant over the north-north-westerly set of faults which are probably extensions into the area from the Brampton district to the south (Trotter and Hollingworth 1932, p. 8, fig 1). In the South-eastern Area (b) the pattern is more complex, but points of similarity with (a) emerge, particularly as regards the north-north-easterly fold axes, although north-westerly trending faults are more prominent. The pattern derived from structures within area (c) is simple; it represents a major group of faults trending east-north-east and a minor group trending approximately north-west. This rose shows a slight resemblance to those for parts of north Northumberland (Westoll and others 1955, p. 87, fig. 1).

DETAILS

WESTERN AREA

Much of the southern part of the western area is masked by thick drift so that the map gives an impression of simple structure. However, the variation in dips at isolated outcrops suggests that the area north and north-east of Solport Mill [466 714] may be complex and affected by hidden faults. In the drift-free areas, the dominant fold axes and fault-lines are seen to be north-north-easterly. Several of the north-north-easterly faults cross the northern margin of the district into the Kielder Castle (7) district; they are, from west to east, the Kershope, Wythes and East Skelton faults. The Wythes and East Skelton faults join about ½ mile S. of the northern margin of the district to become the Lazy Knowe Fault of the Kielder Castle district. Much subsidiary faulting can be seen in Riding Grain and its tributaries. Between the Kershope and Wythes faults dips are moderate and mainly to the east and south-east; east of the East Skelton Fault the measures capping Glendhu Hill [568 865] dip gently to the south-east.

Kershope–Dappleymoor Fault. In the northern part of the district the Kershope Fault runs close to and parallel with the Scottish Border and is joined from the east by the east–west Bailey Hope Fault ½ mile N. of English Kershope [526 848]. North of this intersection the throw of the Kershope Fault is down to south-east, but south of the intersection it is down to north-west. Farther south the Kershope Fault is joined from the west-south-west by the Kershopefoot Fault. South-south-westwards from this junction the Kershope Fault runs parallel to and west of the Routledge Burn Anticline, being separated from it by a complementary syncline. The anticline is expressed in the tight folding of the Bogside Limestone in Routledge Burn, of the thick algal limestone beneath the Ashy Cleugh Limestone in Crubinshill Sike and of the Ashy Cleugh and Rigghead limestones in Crook Burn. Both folds can be traced at least as far south as the west-south-westerly Bellevue Fault which has a southerly downthrow and which joins the Kershope Fault near Arthur Seat [495 783]. About 450 yd farther south the Kershope Fault is joined from the west-south-west by the Parkhouse Fault which also throws down south. It is possible that the Bellevue and Parkhouse faults represent an early fracture which became displaced by the later Kershope Fault. It is also possible that the north-north-easterly anticlinal axis passing through Chamot Hill [484 772], south of the Parkhouse Fault, may be the laterally-shifted continuation of the Routledge Burn Anticline. However, there is no evidence of the continuation of the complementary syncline in the drift-covered ground west of Chamot Hill.

Farther south the Kershope Fault changes direction to south-east, and under the name

Dappleymoor Fault it forms the western boundary of the Oakshaw Coal-basin. The fault plane can be seen, dipping at 75° to the south-west in the River Black Lyne [499 746] ¼ mile S.E. of Trough Farm, where it is associated with several minor sub-parallel and cross-faults. The south-eastern end of the fault passes below the plane of the Goat Island–Lyne Thrust [5102 7397] ¼ mile N.N.E. of High Parkfoot.

Kershopefoot Fault. West of Golden Cleugh, the Kershopefoot Fault, throwing down south, brings beds of the lower part of the Upper Border Group against the topmost measures of the Middle Border Group which include the Kershopefoot Basalt. The throw of the fault is small between Kershopefoot village and Kershope Bridge [502 834], but where it intersects the Liddel Water [4711 8202], its throw is increased by cross-faulting to between 1500 and 2000 ft, for some, if not all, of the Cambeck Beds, the whole of the Middle Border Group and the lowest 500 ft or so of the Upper Border Group are cut out.

South of the Kershopefoot Fault. Between the Kershopefoot, Parkhouse, Back Burn, and Kershope faults, the structure is obscure, but a broad syncline appears to be present, its axis extending north-eastward from Hirsthead Sike parallel with the Liddel Water to cross the Kershopefoot Fault about ½ mile S.E. of Kershopefoot village. The northward extension of this fold across the fault accounts for the arcuate outcrop of the Kershopefoot Lava, partly shown on the adjoining Langholm (11) Sheet of Scotland.

The Lawston Limestone crops out in the Liddel Water on the western limb of the same fold; its outcrop on the opposite limb may be represented by the north-westerly dipping limestone formerly quarried at Leagair [474 794]. Near the head of Long Cleugh [487 809] a gentle anticline appears to be complementary.

Back Burn and Hilltop faults. Farther south, towards Penton and Riddings, two sub-parallel north-easterly faults, both throwing north-west, enclose a narrow tract of country about 4½ miles long and underlain by Liddesdale Group rocks. The easternmost is the Back Burn Fault which can be seen as a vertical shatter-belt in Back Burn [438 747] and Hagling Burn [448 759] and can be traced into the Catlowdy area. The Hilltop Fault (misnamed 'Hillton' Fault by Barrett and Richey 1945, p. 29) has been mapped as separating the steeply inclined Liddesdale Group rocks from the gently dipping Upper Coal Measures exposed in the Liddel Water. However, the Hilltop Fault is nowhere seen and it is possible to interpret the structure as a monocline with a north-north-easterly axis. In this connexion it should be noted that Liddesdale Group rocks exposed in the upper end of the Chapel Burn near Kingfield House [456 778] also dip steeply north-westwards, though the ground between the burn and exposures in Carwinley Burn [422 734] is heavily drift-covered.

West of the Hilltop Fault. The Archerbeck Fault forms the northern boundary of the Coal Measures at Penton; Upper Coal Measures to the south are thrown against the Penton Coals (Millstone Grit Series) to the north, thus implying a southerly downthrow of between 3000 and 3500 ft.

A small, structurally complex area underlain by rocks of Upper Liddesdale and Millstone Grit age lies between the east–west Archerbeck and Watleyhirst faults (Fig. 33). These measures are well exposed in the Liddel Water for some distance above and below Penton Bridge [433 774] and are folded into two anticlines with a connecting syncline. The westernmost fold, the Penton Anticline (Frontispiece), is asymmetric and has been figured by Pringle (1948, pl. IV). The Kilnholme Syncline, to the east, is a more open fold, with a sinuous axis which can be traced from Kilnholme northwards to a locality 200 yd E. of Hogwash. At both places the Tombstone Limestone forms the core of the fold. West of Kilnholme several sub-parallel minor folds of small amplitude can be seen in the river. The easternmost fold is the Peter's Crook Anticline, the axis of which crosses the Chapel Burn midway between its mouth and the railway. Farther north, in the Liddel Water near Cat Linns [442 782], a sequence extending between the Linns and Harelawhill limestones dips eastwards at moderate angles on the eastern limb of the fold.

The Penton Linns Fault, visible in the Liddel Water at three localities [431 773; 434 773; 437 774], is mapped as branching from the Archerbeck Fault on the adjoining ground across the Scottish Border. Millstone Grit Series coals, formerly worked at Penton, are preserved on its southern, downthrow side. Cross-faults and differences in the attitudes of beds to north and south contribute to a considerable variation in the amount of throw along the trace of the fault. The axis of the Penton Anticline abuts against the northern side of the fault about 50 yd W. of Mill House [432 772], but south of the fault the axis cannot be traced. There appears to be a uniform south-easterly dip between the beds exposed on the south side of the fault at Blae Pot and those in the railway cutting 300 yd to the east; the moderate south-easterly dip of the Catsbit Limestone and overlying beds south of the fault at Blae Pot contrast with the steep westward dip of the Harelawhill and associated limestones which lie in the western limb of the Penton Anticline north of the fault, at the same locality. However, the dip of the Catsbit Limestone agrees in amount and direction with the dip of the gentler eastern limb of the Penton Anticline at Penton Bridge. It is inferred, therefore, that the Catsbit Limestone at Blae Pot may lie on the eastern limb of the southerly continuation of the Penton axis, and that the latter has undergone a lateral, dextral shift. Corresponding shifts in the other fold axes cannot be traced for north–south cross-faults between Shankend [437 772] and Penton Mill [433 773] obscure the pre-fault structures.

The Penton Linns Fault is almost directly aligned with the Parkhouse and Bellevue faults—both thought to be at least partly transcurrent—farther east, and it is possible that these fractures represent an originally continuous fault which became displaced by later north-north-easterly faults. If this theory is correct, there should be a connecting structure in the drift-covered ground between the Hilltop and Back Burn faults.

South-east of the Back Burn Fault. The structure is obscured by thick drift in the area drained by the Rae Burn and its tributaries south-east of the Back Burn Fault. Farther to the south-east, beds exposed in the River Lyne between the Lynedale and Brackenhill faults are folded into a gentle synclinal basin with an apparent north–south axis. The structure passes southwards beneath the Permo-Trias and is truncated to the north by the southerly throwing Pallyards Fault.

North-east of Solport is a triangular area of Liddesdale Group rocks, bounded to the east by the Goat Island–Lyne Thrust and to north and west respectively by the Friarhillgate and Lynedale faults. The latter, together with a branch-fault, can be seen in the River Lyne [478 707; 479 708].

Oakshaw Syncline. West of the Hole of Lyne Fault a gentle north-north-easterly syncline includes the Oakshaw Coal-basin. The southern end of the synclinal axis passes below the Goat Island–Lyne Thrust near Dappleymoor, and to the north it crosses the Todholes Fault, the axial direction swinging through north to north-north-west in the Holehead [522 784] area as it approaches the Bellevue Fault. The latter affects the axis dextrally by about half a mile and, north of the fault, it resumes its normal north-north-easterly trend from Black Knors [534 802] towards Skelton Pike [542 836] where it merges with the western branch of the East Skelton Fault.

The north–south Cuddy's Fault lies midway between the Routledge Burn Anticline and the northerly continuation of the Oakshaw Syncline. Cuddy's Burn follows the line of the fault, and dips of strata exposed in the stream display great variation in amount and direction. West of Cuddyshall Bridge [521 807] the structure is represented by a belt of at least three faults with a net easterly downthrow. Near the junction of Langley and Routledge burns, between High and Low Baileyhead farms, there is an acute north-easterly syncline in Bewcastle Beds; it is probably associated with the Cuddy's Fault which passes close to the east.

SOUTH–EASTERN AREA

Goat Island–Lyne Thrust. The thrust forming the western boundary of this area is a south-westerly branch of the Hole of Lyne Fault which terminates [485 703] west of Crowsikehead. At Goat Island [485 715] it consists of an apparently vertical crush-belt about 30 yd wide, to the west of which the strata are sharply folded. Although there can be little vertical displacement the outcrop of the Goat Island Limestone on both sides of the zone shows that at this locality horizontal movement may be considerable. Measures east of the thrust are nearly vertical; they form part of the western limb of the asymmetric Stapleton Anticline, beneath which the thrust-plane is developed northwards from the island. At the junction of the rivers Black Lyne and White Lyne [495 731], the thrust appears to be a single break; the beds on the northern side, exposed at the mouth of the River Black Lyne, display moderate, normal southerly dips which contrast with a reversed easterly dip of 50° to 70° to the south. Contorted strata in the River Lyne, west of Luckens Wood, indicate the presence of the thrust-plane at shallow depth below the river bed and calculation based on the difference in height between this locality and the outcrop of the thrust at a higher level, about 200 yd to the west, indicates that the thrust-plane is inclined to east-south-east at about 1 in 8.

A north-north-westerly structure—the Luckens Fault—is postulated to account for the repetition and westerly offsetting of the vertical, westerly-younging Upper Border Group sequences exposed in the River White Lyne between Lynecrook and Selbystown and in the River Lyne above and below Crabtree Pool. The fracture is nowhere exposed. There are numerous dextral and sinistral, small-scale tear-faults visible in the River White Lyne between Lyneholmeford and White Lyne Bridge and normal to the outcrop of the thrust, but there is no field evidence for strike-slip faulting on this scale.

The Kaysbank Reversed Fault can be seen in the south bank of the River White Lyne [512 728] and in the Kirk Burn about 1½ miles to the south-west. Most of its westerly downthrow is taken up by the intersecting Luckens Fault.

Stapleton Anticline. The Stapleton Anticline is a periclinal structure lying between the Kaysbank Fault and the Lyneholmeford Fault-belt. Its eastern limb is exposed in Kirk Burn, south of Stapleton church, and its axis converges northward with and passes below the Lyneholmeford Fault-belt. Southward it pitches gently below Permo-Triassic strata.

Lyneholmeford Fault-belt. In the River White Lyne, west of Lyneholmeford, the north-north-easterly Lyneholmeford Fault-belt consists of five constituent fractures which enclose narrow tilted blocks of Main Algal or Bewcastle beds. Together these fractures form a steeply dipping reversed fault. The fracture breaks the synclinal fold connecting the Bewcastle and Stapleton anticlines and thrusts the former over the latter in the area north of Lyneholmeford. Farther north, near Roadhead [517 749], it is joined by the Goat Island–Lyne Thrust and continues north-north-eastward as the complex Hole of Lyne Fault.

Hole of Lyne Fault. The Hole of Lyne Fault continues into Northumberland, where it joins with the east-north-easterly Harrett's Linn Fault. Between Roadhead and its junction [548 818] with the northerly branch of the Bellevue Fault, the Hole of Lyne Fault is a steep-angled reversed structure. Farther north it appears to pass into a normal fault with an easterly downthrow; in Robbies Grain the amount of throw is small, but the fault is marked by a wide zone of disturbance. It is assumed, therefore, that the Hole of Lyne Fault pivots from a reversed to a normal fault at a locality near Black Lyne House [545 815] and that there is a further change at its junction with the Harrett's Linn Fault, for the latter has a northerly downthrow (p. 240).

Bewcastle Anticline. The Bewcastle Anticline has a steeply inclined, vertical or reversed western limb. On the eastern limb dips decrease from about 35° near the axis to 7° or 8° three miles to the east. The western boundary of the structure is the north-north-easterly Hole of Lyne Fault.

The similarity of the Bewcastle Anticline to the Holburn and Lemmington anticlines of north Northumberland east of Cheviot has been remarked by Westoll and others (1955, p. 86). All appear to be bounded on their western sides by steep reversed faults or 'break-thrusts', and have eastern flanks traversed by a system of sub-parallel dip-faults. The Holburn and Lemmington folds are interpreted (op. cit., p. 90) as having undergone a rotation of 25° relative to each other, and their associated dip-faults are believed to represent conjugate shear-surfaces. The Bewcastle Anticline seems, nevertheless, to be a more complex structure than either of the Northumbrian folds. The initial north–south compression gave rise to gentle doming of the strata about an east–west axis around what is now Bewcastle village and the southern flanks of this structure can be discerned in the 2½-mile stretch between Gillalees [570 713] and Show Burn.

The subsequent intense east–west compression—presumably responsible also for the Holburn and Lemmington anticlines in Northumberland—sharply refolded the dome along a north-north-easterly axis and later caused the folded measures to shear and thrust along the line of the Hole of Lyne and associated faults.

Westoll and others (1955, p. 90) explain the Holburn and Lemmington folds and their bounding 'break-thrusts' as representing 'reaction to the presence of the Cheviot mass'. No comparable rigid mass is apparent at outcrop in the Bewcastle district, although there may be one at depth in the area north or north-east of Roadhead.

During the compressional phase the southern flanks of the earlier dome became fractured by north–south faults, and the fault-blocks so formed were tilted to the west. The Goat Island Thrust developed ahead of the Lyneholmeford–Hole of Lyne complex. Thus the crest of the Bewcastle Anticline in the area east of Stapleton underwent a greater lateral shift than the ground to the north, and a sinuous form was imparted to the main fold axis (Fig. 33). The radiating dip-faults on the eastern flanks of the anticline probably represent rotational shear-planes.

Mewsgate, Low Park and Askerton faults. The Mewsgate Fault lies east of the axis of the Bewcastle Anticline. It is marked by a belt of vertical strata in the Show Burn [524 723] west of Low Floweryhirst, but its continuation south of this locality is conjectural. Its easterly downthrow is variable because of an intersecting cross-fault and of differing attitudes of beds on opposing sides of the fault. It is assumed to have shifted the outcrop of the nearly horizontal Permo-Triassic strata by at least 2 miles northward on its eastern side.

The Low Park Fault continues southwards into the Brampton (18) Sheet to join a fracture which Trotter and Hollingworth (1932, p. 7 et seq.) took to be the northern extension of the Pennine Fault. The fault forms a narrow crush-belt in Cam Beck [542 695]. Between it and the sub-parallel Askerton Fault, about one third of a mile to the east, is a narrow belt of westerly tilted Cambeck Beds, which are repeated about one mile to the north-east by a series of branch-faults. The two faults join farther north to become the Bogside Fault which continues northwards with diminishing throw before ending against one of the radial faults cutting the eastern and south-eastern flanks of the Bewcastle Anticline.

Between the Low Park and Antonstown faults. The North Upper Denton and Waterhead faults enter the district from the adjoining Brampton district to the south. Both are north-westerly structures throwing down to the south-west. The North Upper Denton Fault dies out to the south of the Shopford Fault which appears to be a continuation *en echelon* north-westwards of the Waterhead Fault. The Gilsland Fault-belt, farther east, represents the north-western extension of the Blenkinsopp Boundary Fault of the Brampton district. The belt comprises five parallel branches which enclose alternating horsts and troughs (Fig. 33). These faults die out north-westwards towards the King Water.

A system of rotational shear-faults is radially disposed relative to the Bewcastle Anticline in the quadrant between the Askerton and Antonstown faults. Several of the fractures display arcuate traces, concave northwards, and both branch-faults and cross-faults are common. Most of the faults die out in the softer shaly sequence of the Lynebank Beds towards the centre of the anticline.

Farther north, between Ashy Croft [567 770] and White Preston [594 771], a narrow belt of Main Algal and Cambeck beds is enclosed between the Antonstown Fault and a curving, sub-parallel branch-fault. The beds are considerably crushed and distorted; east of Ashy Croft the branch-fault throws down north and surface features indicate a gentle easterly dip, but at White Preston dips in Main Algal Beds on the eastern flank of the hill are westerly, and the same fault throws down to the south. Thus White Preston forms a fault-enclosed horst. A belt of shattered but mainly vertical strata about 50 yd wide marks the position of the Antonstown Fault in the headwaters of Ashy Cleugh; elsewhere its course is indicated by numerous sink-holes and springs.

Little structural information is available in the heavily drift-covered Spadeadam Waste area, but farther east between Shankend [687 767] and Lampert [682 746], the parallel Lampert and Spy Rigg faults are exposed in the Irthing valley. The downthrows of these faults vary in direction and amount because of intersecting cross-faults which have larger displacements than either of the directionally dominant parent fractures. Thus the Spy Rigg and Lampert faults enclose a horst south of Lampert and a trough west of Spy

Rigg. The faults post-date two east–west folds of small amplitude; a faulted syncline north of Lampert is complementary to an anticline through Spy Rigg [689 758]. The latter is aligned with a similar small east–west anticline exposed in Bull Cleugh 6 miles to the west, but it is not known whether the structures are continuous. J.B.W.D.

NORTH–EASTERN AREA

Between the Antonstown and Beckhead–Binky Linn faults. For most of its course the Antonstown Fault follows an east-north-easterly trend, but towards the Bewcastle Anticline it swings to north-west and dies out before reaching the anticlinal axis. The downthrow is to the north with a maximum displacement of about 1000 ft around Cammock Rigg [613 778] where it shifts the outcrop of the Whitberry Band by nearly 2 miles.

The surface trace of the Black Stantling Fault follows a sinuous course sub-parallel to that of the Antonstown Fault and with a similar northern downthrow increasing eastwards from about 200 to 500 ft. Two major north-easterly fractures lie between this structure and the Beckhead–Binky Linn Fault. They are the Rough Grain Fault, with a south-easterly downthrow increasing north-eastwards from about 150 to 700 ft, and the East Christianbury Fault, which has a north-westerly displacement of 300 to 500 ft.

Farther east, the principal faults have north-westerly trends. They are from west to east: the Black Knowe Fault, down north-east about 500 ft; the Blackcleugh Burn Fault, down north-east, the throw increasing southwards; the Whickhope Nick Fault, down north-east about 400 ft; and the Reeker Pike Fault, down south-west about 200 ft.

Almost centrally in the trough between the Antonstown and Beckhead–Binky Linn faults is the Humblehill Anticline, trending east-north-east. Minor north-north-easterly folds of small amplitude are also developed on the northern side of the Black Stantling Fault and its northern branch-fracture. Close to the Horse Head Fault are several small folds trending parallel or at right angles to the fault. Between the Black Knowe and Blackcleugh Burn faults an east-north-easterly north-facing monocline crosses Humble Burn [6375 8284] and Smooring Sike [6425 8300]; and a small east-north-easterly anticline crosses the head of Gulley Sike [6465 8274].

Between the Beckhead–Binky Linn and Harrett's Linn faults. The Beckhead–Binky Linn Fault follows an arcuate east-north-easterly course with a southerly downthrow of about 1500 ft near Beckhead Crag increasing to 2000 ft farther east near its intersection with the Kyloe Fault. In the west it is displaced by the Hole of Lyne Fault and continues westward as the Bellevue–Parkhouse faults.

The ground between the Beckhead–Binky Linn and Harrett's Linn faults is almost unfaulted and is characterized by very gentle easterly dips. Exposures in Lishaw Burn include a north–south syncline [5952 8418] and a parallel anticline 60 yd to the east. A broad east-north-east syncline pitching in the same direction passes through Broomylinn Farm.

The Harrett's Linn Fault is a major fracture which splits westwards into a southern branch which is continued as the Hole of Lyne Fault and two western branches which reunite to form the Bailey Hope Fault. The latter is displaced across the East Skelton and Wythes faults. Traced eastwards, the Harrett's Linn Fault passes in an east-north-east direction into the adjoining Kielder Castle (7) district, but it there swings round south-eastwards to re-enter, for a short distance, the Bewcastle district north of Burnt Tom [626 871]. The generally eastward dips are greater on the northern, downthrow side of the fault than on the southern side and the apparent throw therefore increases eastwards from about 1500 ft near the Lewis Burn headwaters to the order of 5000 ft near Burnt Tom.

North-east of the Kyloe Fault. The Kyloe Fault is a large fracture, with a north-easterly downthrow which decreases south-eastwards from nearly 4000 ft where it joins the Harrett's Linn Fault to about 1000 ft at the eastern margin of the district.

North-east of the fault, the dip is generally between east and north-east, except in the area around Little Cranecleugh Burn where the dip is to the north, and in the ground south of White Sike it is to the south-west. An east-north-easterly syncline starts at the north-eastern corner of the district, extending about two miles east to near Falstone, in the Elsdon (8) district; there is a complementary anticline to the north. A flaggy sandstone in Whickhope Burn [6893 8650], 420 yd E.N.E. of Whickhope Lodge, is folded into a north-facing monocline with an amplitude of about 10 ft.

D.H.L., D.A.C.M.

REFERENCES

BARRETT, B. M. and RICHEY, J. E. 1945. Economic geology of the Canonbie Coalfield. *Wartime Pamph. geol. Surv. Gt Br.*, No. 42.

PRINGLE, J. 1948. The south of Scotland, 2nd Edition. *Brit. Reg. Geol.*

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

WADGE, A. J. 1967. In *Summ. Prog. Geol. Surv. Gt Br.* for 1966, 72–3.

WESTOLL, T. S., ROBSON, D. A. and GREEN, R. 1955. Guide to the geology of the district around Alnwick. *Proc. Yorks. geol. Soc.*, **30**, 61–100.

Chapter XIII

IGNEOUS ROCKS

GENERAL ACCOUNT

IGNEOUS ROCKS are of minor occurrence in the Bewcastle district. They include extrusive rocks of Lower Carboniferous age and two groups of tholeiitic intrusions (mainly dykes), the older of which is late Carboniferous or early Permian, while the younger is Tertiary.

The extrusive rocks form the outer fringe of the extensive Lower Carboniferous eruptions in the Langholm district farther north (Scottish Sheet 11). They are represented by the Rawney Tuff in the Lower Border Group, by the Kershopefoot basalt lava in the Middle Border Group and by the Oakshaw Tuff and a somewhat younger tuffaceous limestone in the Upper Border Group. An agglomerate neck in a tributary of Langley Burn is assumed to be only slightly younger than the Upper Border Group sediments which it cuts.

Most of the dykes follow the east-north-easterly alignment which is generally accepted to be the trend of the late Carboniferous or early Permian dyke intrusions associated with the Whin Sill; of these the most important is the Lewis Burn–Troughend Dyke-echelon. A few dykes have a north-westerly trend which suggests that they are members of one of the Tertiary dyke-swarms; the most notable of this group crops out in the River Irthing, near Wiley Sike. Exposures of dolerite in Thief Cleugh and a neighbouring stream have been mapped as a sill though field relationships are obscure. J.B.W.D.

Most rocks of the Lewis Burn–Troughend Dyke-echelon petrographically resemble the general run of quartz-dolerites of the North of England. By contrast, the north-westerly dyke described from the River Irthing, is distinctly tholeiitic, with a slight excess of plagioclase over pyroxene, absence of olivine, equidimensional granular augite and virtual absence of anorthite—all indicating an affinity with the Acklington type (Holmes and Harwood 1929, p. 11). However, some of the east-north-easterly dykes, and even parts of the Lewis Burn–Troughend Dyke-echelon, contain tholeiitic tendencies due to the developments, commonly patchy, of intersertal mesostasis. For some of these specimens, it is difficult to assign a classification to either quartz-dolerite or tholeiite, though the trends show a general affinity with the former. R.K.H.

DETAILS

LAVA

Kershopefoot Basalt. The Kershopefoot Basalt straddles the border with Scotland along the Kershope Burn in an arcuate outcrop more than 2 miles long, terminated at each end by faults. It has a maximum thickness of 120 ft and lies near the top of the Middle Border Group, at least 200 ft below the known base of the Glencartholm Volcanic Beds exposed in the River Esk (Lumsden and others, 1967). Peach and Horne (1093, p. 847) followed the primary surveyors on both sides of the border in believing the mass to be a lava, although subsequent workers (e.g. Garwood 1931, p. 124) referred to it non-committally as 'basalt'. The upper and lower contacts are not exposed and the possibility cannot be ruled out that the basalt is a sill. However, local evidence of vesicularity and slagginess near the top of the basalt suggests an extrusive origin and it is so shown on the map.

Macroscopically the rock, an olivine-basalt, is dark grey to bluish grey and commonly porphyritic, with phenocrysts ranging up to 6 mm in length. Thin sections (E 2285–8; 26255–7) display phenocrysts of shadow-zoned plagioclase, mainly of labradorite composition, pinkish augite and olivine, the latter replaced by carbonate, chlorite, serpentine-group minerals and quartz. Cores of unreplaced olivine (Plate XIV, fig. 1) are in optical continuity with reaction rims of clinopyroxene, having refractive indices $\alpha = 1{\cdot}696$, $\beta = 1{\cdot}698$, $\gamma = 1{\cdot}724$ (all $\pm$ 0·002 2V (+) about 45°. Augite poikilitically encloses plagioclase laths. The suite of phenocrysts suggests an affinity with the Dunsapie type of macroporphyritic olivine-basalt. The groundmass consists of labradorite (near $Ab_{42}An_{58}$; $\beta = 1{\cdot}563$) laths, averaging 0·2 × 0·02 mm, strongly flow-banded in the higher specimens, and generally in ophitic arrangement with anhedral to subhedral augite. Titaniferous magnetite, leucoxenized ilmenite, orthopyroxene and apatite are minor accessories. Mesostasis consists of chlorite and hematite. Vesicles are infilled with chlorite, calcite and chalcedony, with amethyst at low levels within the mass. Chlorite, carbonate and hematite are the main alteration products. R.K.H.

One specimen (E 26261) shows a contact of feldspar-phyric olivine-basalt with calcareous chert probably forming part of a neptunian dyke. The basalt is highly altered: olivine is replaced by chlorite-serpentine, groundmass feldspars are albitized, and the zoned phenocryst feldspars are saussuritized. The irregular contact zone shows protrusions of basalt into chert and of chert into basalt.

A yellow-weathering dolomite-siltstone (S 482289) is seen in the Kershope Burn [4974 8332] within about two feet of the top of the basalt. This sediment is highly brecciated by veins of ankerite and joint surfaces are coated with bitumen and with a patchy greenish colouration attributable to redistributed chlorite. Grains and patches of pyrite are visible and some degree of recrystallization is indicated. On the assumption that the basalt is a lava, as indicated by its slaggy top, the slight recrystallization of the overlying dolomite as well as the presence in it of hydrocarbon and chlorite are attributed to diagenesis.

The basalt is again exposed about 3 miles to the north-east in Craggy Cleugh [5317 8552], where the beds are vertical, and where the base of the basalt is cut out by the Kershope Fault. About 60 ft of basalt can be seen; the upper part is typically slaggy at the downstream end of the exposure, but contact with overlying sediments is not exposed.

J.B.W.D.

Thin sections (E 26266, 31062) exhibit phenocrysts, up to 3 mm long, of plagioclase, veined and rimmed with chlorite, set in a markedly flow-banded groundmass of plagioclase laths (averaging 0·2 × 0·04 mm) replaced by carbonate and chlorite, and charged with magnetite cubes and leucoxene dust. Though highly altered, these specimens are similar to those from Kershopefoot.

R.K.H.

TUFFS AND AGGLOMERATE

Rawney Tuff. The Rawney Tuff is exposed in Bothrigg Burn, to north [5500 7645] and south [5479 7602] of Rawney Cottage; from time to time both exposures are temporarily obscured by local landslip. At the northern outcrop about 1½ ft of dark brownish black brecciated scoriaceous calcareous tuff can be seen in association with bands of algoolite. Below the tuff are about 4 ft of sharply folded striped calcareous mudstone (p. 23) and above are 2½ ft of moderately folded, but disturbed and broken calcareous shales, with limestone bands. J.B.W.D.

A thin section (E 25902) displays angular brown to buff phenoclasts in roughly parallel array, though individually contorted. They are composed of banded microcrystalline, dusty calcite, with illite and a little fine quartz. The phenoclasts have been extensively replaced by coarser calcite matrix with scattered clastic quartz and sulphide grains. Though the phenoclasts show some resem-

EXPLANATION OF PLATE XIV

Photomicrographs of igneous rocks and associated clastic rocks

FIG. 1. Olivine-basalt; Kershopefoot Basalt, Kershopefoot [481 827]. E 2287.
Partly replaced olivine phenocryst (clear, upper left of field) is rimmed by clinopyroxene and chlorite. The groundmass consists of finely crystalline, flow-banded plagioclase, granular pyroxene and specks of titanomagnetite.
Partly crossed polars × 30.

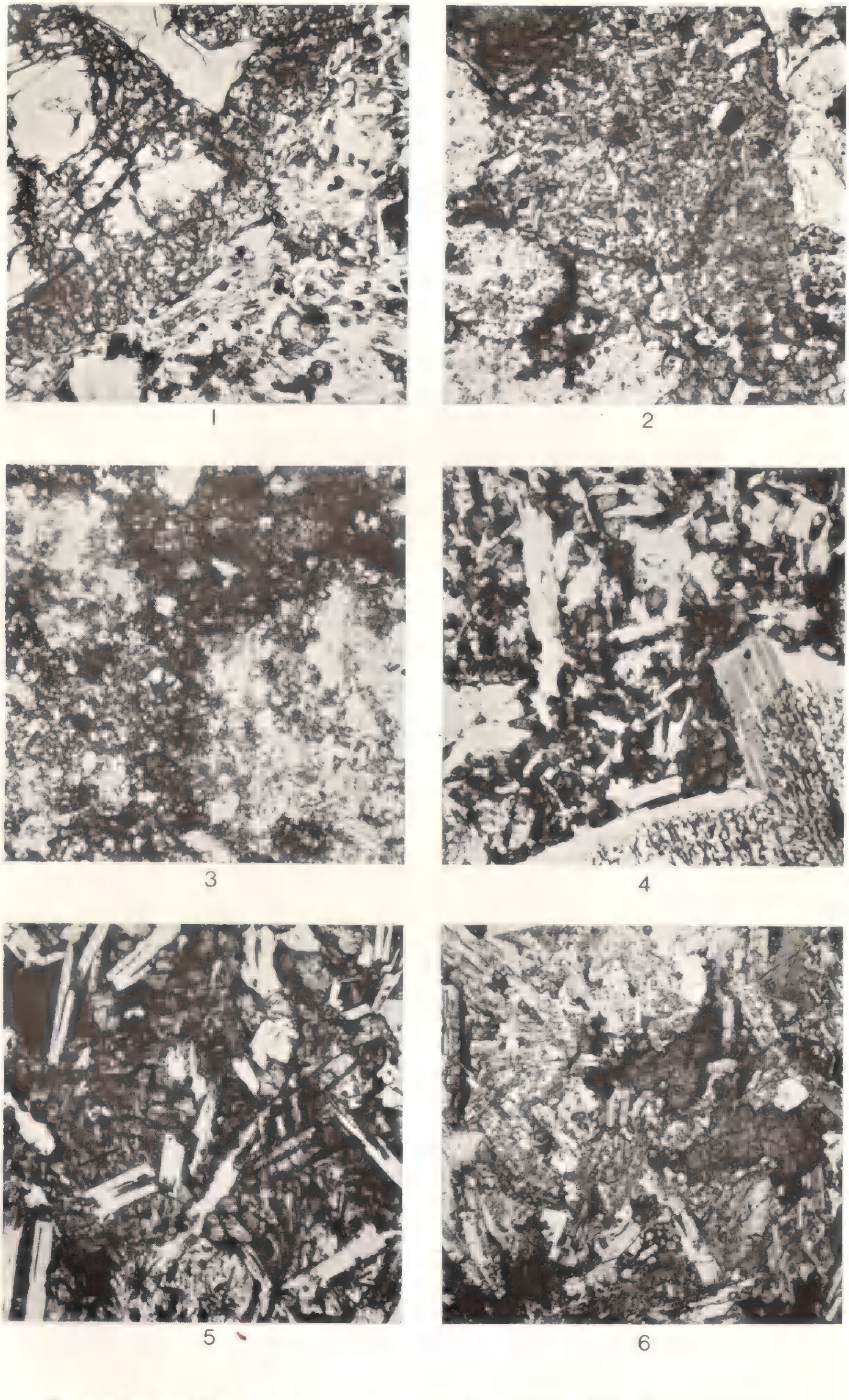
FIG. 2. Oakshaw Tuff, exposure [5047 7579], 330 yd N. 46° E. of Dodgsontown Farm, S. bank of R. Black Lyne. E 25904.
Rather rounded lithic particles, include felsitic and porphyritic lava, closely packed in a dolomite-rich matrix, partly clastic and partly secondary, with calcite, iron oxides and clay minerals. Partly crossed polars × 44

FIG. 3. Agglomerate (matrix), Harry's Sike [5056 8238]. E 26272.
Highly altered lapilli of lava (lower right and upper left of field) have been replaced by carbonate, yet retain characteristic felsitic texture.
Nearly crossed polars × 47

FIG. 4. Dolerite, Thief Cleugh [4919 8273]. E 26260.
A phenocryst of labradorite (lower right) exhibits zonary micrographic inclusions, and is set in an ophitic groundmass of labradorite laths, granular augite, skeletal ilmenite and minor mesostasis. Nearly crossed polars × 44

FIG. 5. Tholeiitic quartz-dolerite. Black Cleugh [5599 8230]. E 33485.
Ophitically arranged, magmatically corroded, labradorite laths are randomly oriented with granular pyroxene, skeletal titanomagnetite and accessory quartz. Abundant mesostasis (mainly left centre of field) is patchily developed and the rock assumes a tholeiitic appearance. Partly crossed polars × 45

FIG. 6. Quartz-dolerite. Short Cleugh [627 870]. E 32791.
Ophitic groundmass composed of labradorite laths and replacive, subhedral augite (dark grey). There is accessory orthopyroxene, skeletal titanomagnetite, minor intergranular quartz, hornblende, biotite and apatite.
Partly crossed polars × 48



1 2 3 4 5 6

Photomicrographs of igneous rocks and associated clastic rocks

blance to lapilli, extensive alteration obscures their identity. The field evidence, however, strongly suggests a volcanic origin for this bed. R.K.H.

Oakshaw Tuff. The Glencarthholm Volcanic Beds, which crop out on the Scottish side of the border in the River Esk and were proved in the Archerbeck Bore (Lumsden and Wilson 1961), are represented in the Bewcastle district by the Oakshaw Tuff. It lies a few feet above the base of the Upper Border Group and takes its name from a disused quarry [5723 7606] at Oakshaw Ford where the section is:

	ft	in
Limestone, hard	4	0
Limestone, hard, greenish tuffaceous		6
Tuff, soft		3
Tuff, hard, calcareous ..		6
Tuff, coarse, green, with a few shells		9
OAKSHAW LIMESTONE ..	11	0

The bed achieves local maximum thickness of 3 ft in the River Black Lyne [5049 7578], ½ mile W.S.W. of the quarry, and is also exposed in a ditch [5783 7577] north-east of Nether Oakshaw, where it is coarse and infills cracks in underlying shales. There is no representative of the bed farther west, though an unusual limestone containing tuffaceous debris occurs about 50 ft higher in the sequence in the River Black Lyne [4990 7504] west of Cumcrook Farm. J.B.W.D.

Thin sections (E 14186, 25904, 31040) of the Oakshaw Tuff show abundant lithic particles of mugearite-trachyte with flow-banded sodic feldspar laths, porphyritic and felsitic lava, devitrified glass, crystal fragments of quartz, potash and sodic feldspars. These lithic and crystal constituents are generally subrounded and closely packed with clastic dolomite in a matrix of iron oxides, clay minerals and carbonate (Plate XIV, fig. 2). Dolomitization of the clastic particles is pronounced, while post-depositional fractures have been infilled with calcite and fine silica. Specimens (E 31515–6) from the higher, tuffaceous bed are similar save for higher proportions of calcarenite and cementing carbonate. R.K.H.

The particles of mugearite-trachyte do not correspond lithologically to the local contemporaneous volcanic rocks, most of which are, like the Kershopefoot Lava, derived from alkaline basaltic magma. Knill (*in* Lumsden and Wilson 1961, pp. 70–3) noted a similar discrepancy among the lithic fragments in the Glencartholm Volcanic Beds of the Archerbeck Bore which she described as having affinities with the Borrowdale Volcanic Series of the Lake District, about 30 miles to south-south-west.

Vent Agglomerate. In Harry's Sike, a tributary of Langley Burn, coarse agglomerate is exposed [5056 8238]. The fragments, up to 2 ft in diameter, consist of porphyritic lava and of altered sediments containing carbonaceous inclusions; they are set in a matrix of soft, coarse green tuff. A few yards upstream is an exposure of blue-grey basalt displaying onion-weathering. No contacts are seen and the basalt and agglomerate are therefore mapped as lying within a vent. J.B.W.D.

Specimens (E 26268–73) of the matrix of the agglomerate show a range of bedded, crenulated lapilli of highly altered carbonated, pyritized and ferruginized felsitic and porphyritic lava, turbid brownish devitrified glass, and microcrystalline quartz-feldspar aggregates with chlorite and dolomite (Plate XIV, fig. 3). These are intermixed with calcarenite, microcrystalline dolomite and clastic quartz in a brownish dolomite (refractive index $\omega = 1{\cdot}684$) cement. R.K.H.

INTRUSIONS

Dolerite Sill. The Great Whin Sill of Northern England does not crop out in the district as it does farther south in the Brampton district (Trotter and Hollingworth 1932, pp. 113–9). However, a dolerite of similar petrographic affinity has been mapped as a sill at outcrop in Thief Cleugh [4919 8273] and farther along the sedimentary strike in a small stream [4990 8291], 850 yd W. of Burntshields Gate. J.B.W.D.

Porphyritic tholeiitic dolerite (E 26260) from the former locality exhibits phenocrysts of labradorite 2 mm in length (Plate XIV, fig. 4), the cores being charged with micrographic inclusions, and enclosed in clear euhedral rims. The groundmass consists of a microcrystalline felt of frayed labradorite laths (averaging 0·4 × 0·04 mm), plentiful interstitial subhedral to anhedral augite, skeletal frameworks of replacive ilmenite and minor mesostasis. Secondary carbonate, chlorite and quartz are present. A specimen (E 26262) from the latter locality is aphyric and more altered than the first specimen, through carbonation and chloritization, and contains a higher proportion of mesostasis. Subvesicles are infilled with chlorite and calcite. R.K.H.

Stonegarthside–Lewis Burn–Troughend Dyke-echelon. An east-north-easterly dyke-echelon traverses the northern part of the district and continues beyond it to the Northumberland coast—a total distance of about 60 miles. Where it enters the district from the west, across the Liddel Water, it is called the Stonegarthside Dyke. It is stepped successively northward as it is followed across the district, the longest segment being the Lewis Burn–Troughend Dyke (Lebour 1878), which extends beyond the northern margin of the sheet into the ground north of Falstone and Elsdon, where it is described by Teall (1884, pp. 239–42) as the High-Green Dyke. Segments of the echelon still farther to north-east, towards the coast, have been dealt with by Carruthers and others (1930, pp. 74–82) and Fowler (1936, pp. 120–4).

At Pudding Crook [4619 8000], on the Liddel Water, the Stonegarthside Dyke is 39 to 40 ft wide and consists of dark blue-grey crystalline quartz-dolerite exhibiting exfoliation weathering, but little sign of baking at the contacts. It extends eastwards for 2 miles as far as Stonegarthside where its position is marked by an exposure of ochreous earth in Kiln Sike [4742 8036] and by a pile of large dolerite boulders at a sheepfold [4885 8054], north-east of Black Seat.

The next segment of the dyke-echelon towards the east-north-east is unnamed. It extends eastwards from Burntshields Gate [5075 8289] to Routledge Burn where it was formerly exposed. A specimen sectioned [E 14185] from the latter locality is a tholeiite consisting of laths of labradorite (0·2 mm) and small granular augite in an interstitial glassy groundmass with skeletal ilmenite and opaque oxides. Pyroxene is replaced by secondary chlorite, and rare, small cavities are filled with calcite.

Another short segment of the dyke-echelon is about 70 ft wide where it is exposed [5364 8453] in the headwaters of Routledge Burn, about 1 mile N.E. of the previous locality. At this exposure the dyke is aligned with the main Lewis Burn–Troughend Dyke, about ½ mile to the east, though in the intervening ground there is an exposure [5421 8424] of a dyke-segment off-set to the south.

The western part of the Lewis Burn–Troughend Dyke is exposed in Lancy's Cleugh [5553 8479] and in the headwaters of the River Black Lyne [5633 8502], on the southern slopes of Glen Dhu. In Lancy's Cleugh the dyke is 69 ft wide and is a greenish grey quartz-dolerite weathered into spheroidal masses surrounded by ochreous earth. Weathering of this kind can be seen in a small quarry nearby to extend for at least 15 ft down from the surface. At the southern margin of the dyke in Lancy's Cleugh there is a small fault with a southerly downthrow of about 10 ft. The shales against the southern margin are baked to a whitish colour; against the north side sandstones, limestones and shales have been altered, some to a greenish colour, although fossils have not been destroyed. Slight alteration of limestones is still evident 20 yd from the northern contact. J.B.W.D.

A metasomatized sandstone (E 33483) from this locality contains greenish spheroids (0·5 mm average diameter), charged with anastomosing streaks, and patches of chlorite (X-ray powder photograph, NEX 267). The spheroids are surrounded by calcite, and have developed in fine feldspathic sandstone, in which the clastics have been extensively replaced. R.K.H.

In the River Black Lyne the dyke is more than 60 ft wide and alters a nearby sandstone. A thin, subsidiary dyke [5618 8493] about 6 ft wide, is intruded parallel to the main intrusion on its southern side. J.B.W.D.

The main dyke—a quartz-dolerite (E 33482)—is aphanitic, and dark grey, consisting of ophitically arranged labradorite laths (averaging 0·3 × 0·04 mm), with refractive index (β) = 1·570, indicating a composition near $Ab_{30}An_{70}$. Clinopyroxene forms clots of anhedral to subhedral grains, while accessory enstenite occurs in stout prisms, 0·4 × 0·3 mm. Minor accessories include pools of intergranular quartz, amphibole, skeletal titanomagnetite and deep reddish brown biotite fringed with chlorite. The mesostasis is charged with feldspar and

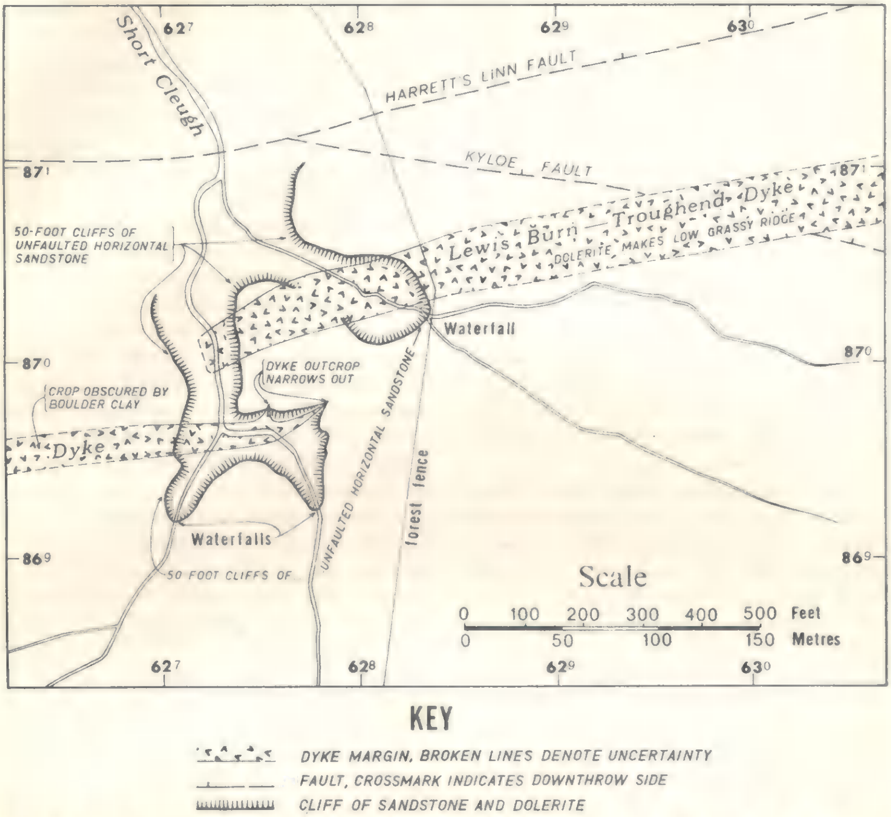

Short Cleugh
62⁷
62⁸
62⁹
63⁰
HARRETT'S LINN FAULT
KYLOE FAULT
87¹
87⁰
86⁹
50-FOOT CLIFFS OF UNFAULTED HORIZONTAL SANDSTONE
Lewis Burn — Troughend Dyke
DOLERITE MAKES LOW GRASSY RIDGE
Waterfall
DYKE OUTCROP NARROWS OUT
CROP OBSCURED BY BOULDER CLAY
Dyke
UNFAULTED HORIZONTAL SANDSTONE
forest fence
Waterfalls
50 FOOT CLIFFS OF
Scale
0 100 200 300 400 500 Feet
0 50 100 150 Metres
KEY
DYKE MARGIN, BROKEN LINES DENOTE UNCERTAINTY
FAULT, CROSSMARK INDICATES DOWNTHROW SIDE
CLIFF OF SANDSTONE AND DOLERITE

FIG. 35. *Sketch-map showing the Lewis Burn-Troughend Dyke offset at Short Cleugh*

apatite microlites, and with micrographic growths of probably potash feldspar and quartz.

Farther east the dyke crosses the head of Lewis Burn, 2¼ miles W.S.W. of High Long House. A specimen from this locality is seen in thin section (E 1350) to be a tholeiitic quartz-dolerite with only scattered phenocrysts, mainly of pyroxene. The ophitic groundmass comprises labradorite (near $Ab_{42}An_{58}$) laths, averaging 0·5 × 0·1 mm commonly saussuritized and coarser (0·4 × 0·2 mm) plates of pale brown augite. Accessories include skeletal ilmenite or titanomagnetite, apatite needles, a little quartz and hornblende. Minor intersertal mesostasis consists of a dusty intergrowth of feldspar and quartz charged with microinclusions. There is a little secondary chlorite and pyrite. A modal analysis gave, in volume per cent: plagioclase 43; augite 31; hornblende 2; quartz 5; ilmenite, titanomagnetite 7; mesostasis 10; pyrite ½; chorite ½. R.K.H.

Farther east the dyke is generally 80 to 90 ft wide, and continues along an east-north-easterly strike with *en echelon* steps to the north. One of these *en echelon* steps is clearly exposed (Fig. 35) in Short Cleugh [627 870] north-east of Burnt Tom, where the cleugh is bordered by 50-ft cliffs of horizontal, massive sandstone which is unfaulted and, except where cut by dolerite, continuous. Followed eastward the dyke is first seen in the western side of the cleugh where it is about 55 ft wide; from there it can be traced in the floor of the main cleugh before narrowing out in two north-easterly projecting fingers. The dyke outcrop is resumed *en echelon* about 50 yd to the north where it is about 70 ft wide in the east wall of the main cleugh and absent from the west wall. The dyke dips to south-south-east at 80° at this locality. It can be traced into and across the eastern tributary cleugh, where it is about 95 ft wide, and thereafter towards the east-north-east as a low grassy ridge. D.H.L.

The dyke at Short Cleugh is a melanocratic quartz-dolerite (E 32791) with phenocrysts up to 2 mm in length, of labradorite set in an ophitic mesh of labradorite laths (0·2 × 0·07 mm) near $Ab_{48}An_{52}$, and pale brownish green augite (Plate XIV, fig. 6). Accessory hypersthene, largely altered, forms prisms up to 1 mm in length with frayed terminations and poikilitically enclosing augite. Coarse crystals of titanomagnetite are common, and there is a little interstitial quartz, hornblende, biotite and apatite, with secondary chlorite. R.K.H.

Other *en echelon* gaps in the dyke outcrop within this district are not exposed, though two gaps [5924 8575 and 6001 8598] W.S.W. of High Long House show up clearly on aerial photographs.

A roadside exposure [6099 8633], 150 yd S.S.E. of High Long House, shows the dyke intruded into sandstone. The contact is obscured, but the sandstone within two feet of dolerite is metamorphosed. D.H.L.

Four specimens (E 32787–90) of this sandstone were examined, from the contact and at distances from it of 2, 3 and 15 ft, respectively. All four consist of moderately sorted clastics (0·04 to 0·03 mm), mainly tightly packed with interlocking contacts and much secondary silicification. Detrital feldspars are subordinate. Close to the dyke contact, the sandstone has been modified by the addition of much intergranular untwinned feldspar, which appears (X-ray powder photograph NEX 147) to be mainly albite. Associated with the metasomatic feldspar are illite, and chlorite. Heavy detrital minerals are conspicuous in strings parallel to the bedding and include rounded, colourless and purple zircon, euhedral reddish brown rutile, colourless angular apatite and brown tabular anatase. Veinlets carrying feldspar also occur in the specimen (E 32788), 2 ft from the dyke. An X-ray powder photograph (NEX 2) showed albite and minor chlorite. The chlorite appears to have preceded the albite in the veins. Three feet from the contact little metamorphism is apparent (E 32789) and the sandstone contains allogenic plagioclase, dusty orthoclase and microcline, with sparse chert and quartzite. Sparse matrix includes illite, goethite and leucoxene. The specimen (E 32790) taken 15 ft from the dolerite is similar, with no obvious metamorphism.

The metamorphic effects of the quartz-dolerite on the sandstone are therefore restricted to a distance of about 2 ft from the contact and are seen in the impregnation and veining by sodic feldspar and chlorite, presumably from a late-stage acid residuum of the parent basic magma. Similar feldspathization due to a basic intrusion occurs in Short Cleugh [6273 8697]. R.K.H.

Other Carboniferous–Permian dykes. Several minor dykes of small linear extent are aligned in an arc between north-east and east and are believed to be comagmatic and contemporaneous with the Lewis Burn–Troughend Dyke-echelon. One in Black Cleugh [5599 8230] is about 6 ft wide and indurates adjacent sandstone. Another near the head of Rough Grain [5927 8109] abuts, at its eastern end against the Rough Grain Fault; it is about 40 ft wide and is marked by an exposure of ochreous earth and by loose blocks of amygdaloidal dolerite. Loose blocks of dolerite indicate the position of a further dyke in Heather Sike [6113 8048]. A dyke exposed in Coal Burn [6962 7808] is 22 ft wide and strikes N.83°E.; the contacts are not visible, but shales and sandstones crop out nearby. Farther south, a dyke of greenish dolerite, at least 3 ft wide, crosses the King Water [6043 7280] near Chisholm's Cross on a north-easterly trend. J.B.W.D.

A specimen (E 33485) from Black Cleugh is a dark grey ophitic tholeiitic quartz-dolerite, with even-grained (0·4 × 0·03 mm) groundmass labradorite laths marginally embayed due to magmatic corrosion. Pools of untwinned plagioclase are of mainly labradorite composition. Intergranular augite marginally invades the labradorite. The main accessory is titanomagnetite. Mesostasis is patchily developed (Plate XIV, fig. 5), as a pale brown, crypto- to micro-crystalline undulatory aggregate of devitrified glass charged with feldspar microlites, dark green chlorite, skeletal ore and fine pyroxene. Quartz is mainly associated with secondary calcite. A further specimen (E 33484) from Rough Grain is closely similar except for darker mesostasis and a little orthopyroxene.

The Coal Burn Dyke is seen, in thin section (E 31267), to be a melanocratic medium-grained tholeiitic dolerite. Labradorite laths (0·3 × 0·07 mm), with refractive index (β) = 1·575±0·004, and near $Ab_{45}An_{55}$ in composition, are in ophitic arrangement with, and partly replaced by, pale augite (β = 1·694 ±0·003). Accessory titanomagnetite forms skeletal crystals. Abundant pale brown, patchily developed mesostasis, is charged with microlites and leucoxenic dust. Dolomite, chlorite and a little quartz are secondary.

R.K.H.

Tertiary Dykes. North-westerly dykes of presumed Tertiary age are exposed at three widely separated localities—in Currick Sike, in the River Irthing, and in Tipalt Burn.

The dyke in Currick Sike [5340 8280] is represented merely by 2 ft or more of ochreous earth containing spheroids of dolerite. The intrusion in the River Irthing, however, is seen in the right bank [6515 7020], west of Forster's Hill, to be a complex tholeiitic dyke, 12 to 13 ft thick, following the line of a small north-westerly fault and dipping at 70° to south-west. It forms a marked feature on the opposite bank of the river, though not exposed there. The shales at the south-western contact are baked and have a marked cleavage parallel to the dyke whilst higher up the bank a thin coal becomes first anthracitic and finally cindery towards the margin of the intrusion. At distances of 3 and 5 ft in from the southern contact, and parallel to it, are bands of brecciated and decomposed dolerite respectively (Fig. 36). As both bands are clearly defined in contact with the fresh dolerite adjacent to them, they may be indicative of multiple intrusion.

J.B.W.D.

A fairly fresh specimen (E 31509) consists of a felt of corroded, albite-twinned labradorite laths (0·5 × 0·08 mm) in subophitic arrangement with later, intergranular anhedral to subhedral pale green augite (2V +). Binary-twinned plagioclase is of slightly less calcic composition than labradorite. The main accessory is titanomagnetite. Abundant mesostasis is dark grey, partly isotropic and charged with chlorite, leucoxene and feldspar microlites. Subvesicles, 0·4 mm diameter, are infilled with devitrified glass. Secondary minerals include carbonate,

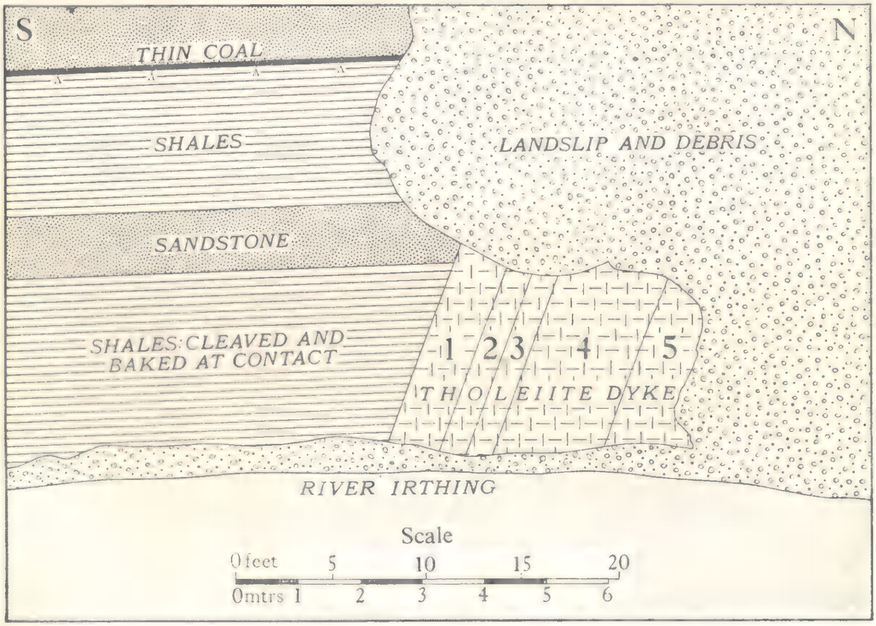


FIG. 36. *Sketch of a ?multiple dyke in the right bank of the River Irthing.*

1. *Medium-grained, dark grey, fresh dolerite, chilled against sediments* .. .. 3 ft
2. *Weathered, brecciated dolerite, with sharply defined contacts* 1 ft to 1⅛ ft
3. *Fresh dolerite like* 1. .. .. 1 ft
4. *Orange-weathering, soft, decomposed dolerite (grey-green where unweathered)* .. .. 5 ft
5. *Fresh dolerite like* 1. *and* 3. .. .. 2¼ ft

chalcedony and chlorite. A modal analysis gave, in volume per cent: plagioclase 37; pyroxene 34; opaque ores 2; chlorite 3; carbonate; mesostasis 23. A fresh specimen (E 31510) from the dyke margin contains a higher proportion of mesostasis, little pyroxene and more pyrite. Both specimens are more closely allied to tholeiites than quartz-dolerites, though phenocrysts are sparse. R.K.H.

The tholeiite dyke in Tipalt Burn is exposed in the left bank, 250 yd W. of Low Tipalt, and has a maximum width of 1 ft 8 in. It trends north-westward in direct line with the dyke in the River Irthing at Foster's Hill, 2 miles away. J.B.W.D.

References

Carruthers, R. G., Burnett, G. A. and Anderson, W. 1930. The geology of the Alnwick district. *Mem. geol. Surv. Gt Br.*

Clough, C. T. 1889. The geology of Plashetts and Kielder. *Mem. geol. Surv. Gt Br.*

Garwood, E. J. 1931. The Tuedian Beds of Northern Cumberland and Roxburghshire east of the Liddel Water. *Q. Jl geol. Soc. Lond.*, **87**, 97–159.

Holmes, A. and Harwood, H. F. 1928. The age and composition of the Whin Sill and the related dikes of the north of England. *Mineralog. Mag.*, **21**, 493–543.

—— —— 1929. The tholeiite dikes of the north of England. *Mineralog. Mag.*, **22**, 1–52.

Lebour, G. A. 1878. *Outlines of the Geology of Northumberland.* Newcastle upon Tyne.

Lumsden, G. I., Tulloch, W., Howells, M. F. and Davies, A. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

—— and Wilson, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

Peach, B. N. and Horne, J. 1903. The Canonbie Coalfield: its geological structure and relations to the Carboniferous rocks of the north of England and central Scotland. *Trans. R. Soc. Edinb.*, **40**, 835–77.

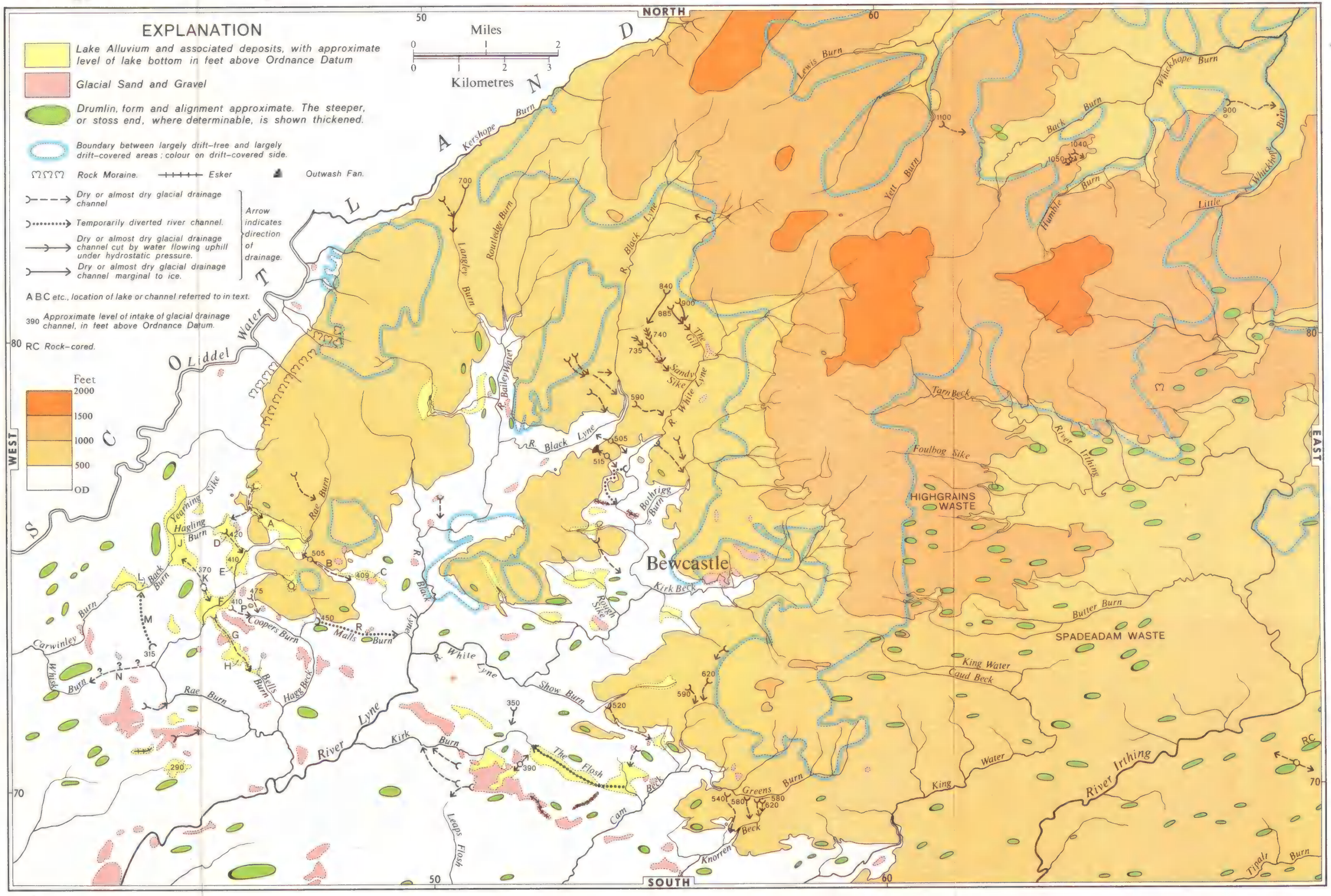
Teall, J. J. H. 1884. Petrological notes on some North of England dykes. *Q. Jl geol. Soc. Lond.*, **40**, 209–47.

---

e 'Newer
upon the
6, p. 50;
ıtion and
ıe glacial
currence,
· boulder
ıstle drift
ınds and

l extends
few local
r ground
ımulated
granites
l erratics
ıf Binky
roduced
ıns than
enclosed
lid rock
Trotter
ıumber-
of the
ntres of
escape
rds into
ewcastle
owards
ıe Lake
wcastle
ither of
ıuthern

s rocks
ıy also
on and
: below
usually



1500/68

MAP SHOWING GLACIAL, FLUVIO-GLACIAL, AND ICE-RETREAT FEATURES

Chapter XIV

GLACIAL DEPOSITS

GENERAL ACCOUNT

THE DISTINCTION between the Lower and Upper Boulder Clay of the 'Newer Drift' in north-west Cumberland is said to depend almost entirely upon the presence of the intervening Middle Sands (Dixon and others 1926, p. 50; Trotter and Hollingworth 1932, p. 147), so that mapping, interpretation and correlation of these sands are fundamental to an understanding of the glacial sequence. However, except for thin lenses of sandy material of local occurrence, none of the sands of the district is seen to be overlain by a younger boulder clay. The evidence is entirely consistent with the view that the Bewcastle drift sequence comprises a single boulder clay overlain by retreat-stage sands and gravels and is related exclusively to the latest or 'Main' Glaciation.

This drift blankets much of the country below the 750-ft contour and extends in places to over 1000 ft O.D. It is assumed, therefore, that except for a few local areas, the whole of the Bewcastle Fells, together with the adjacent lower ground to the south, eventually became submerged by an ice-sheet which accumulated many miles to the west in Galloway. Erratics of Criffel and Dalbeattie granites are commonly found at all elevations, though their replacement by local erratics in an area from Horse Head over Humble Hill to the headwaters of Binky Burn may indicate that the Scottish ice was there inhibited by locally-produced ice. Scattered Scottish erratics are commonly found at higher elevations than boulder clay, and presumably any matrix in which they were formerly enclosed has been removed. Rarely striae may be found on some of the solid rock exposures, indicating a generally eastwards ice movement. According to Trotter and Hollingworth (1932, p. 131) the ice travelled eastwards across Northumberland, its lower portion splitting at Greenhead, part travelling north of the Whin Sill escarpment and part through the Tyne Gap. Ice from other centres of accumulation in the Lake District and on the Alston Block, unable to escape westwards because of congestion in the Irish Sea, moved first northwards into the lower ground between the northern edge of the Pennines and the Bewcastle Fells, met the more northerly stream of ice and was deflected eastwards towards the Tyne Gap. In support of this interpretation rocks derived from the Lake District are occasionally found along the southern margins of the Bewcastle district, but do not extend farther to the north, where the erratics are either of local rocks or of Lower Palaeozoic greywackes and granites from the Southern Uplands.

In areas where it rests on Permo-Triassic or reddened Carboniferous rocks the boulder clay is almost invariably red or reddish. Red boulder clay also extends across rocks which were probably grey at the time of the glaciation and has given rise to superficial reddening along cracks and fissures at and just below rockhead. North of the outcrop of reddened rocks the boulder clay is usually grey or chocolate-coloured where fresh, and yellow where weathered; leaching by humic acid occurs beneath peat.

Sands and gravels in the forms of kames (englacial) or eskers (sub-glacial) are widely distributed throughout most of the southern half of the district, but are absent from the Spadeadam area. Trotter (*in* Trotter and Hollingworth 1932, p. 149) records two major kame-trains converging towards the Tyne Gap. The more northerly, the Gilsland–Kirkcambeck kame-train, can be traced into the Bewcastle district near West Hall [567 678] and extends west-north-westwards, normal to the present primary drainage direction, to its origin near Sunnythwaite [457 746].

Glacial drainage channels are common in the south-west part of the district and also in the valleys of the rivers Black and White Lyne. Marginal channels initially running sub-parallel to the contours as well as the more normal 'downhill' channels are readily distinguished, and channels with 'up and down' profiles crossing topographic divides are thought to have been cut by sub-glacial water flowing uphill under hydrostatic pressure. The distribution of these and other glacial, fluvio-glacial and ice-retreat features is shown in Plate XV.

Details

KERSHOPE BURN CATCHMENT

Reddish boulder clay containing Galloway erratics covers much of the ground up to the 800-ft contour. One or two exposures of grey boulder clay were also noted.

A small mound of sand and gravel occurs on the side of the valley [5138 8428], 500 yd N.E. of Golden Rocks, and a section measured in the side of a forest road shows 2 ft of clayey gravel with erratics on 6 ft of ill-graded coarse to fine sand containing rounded and sub-angular grains.

A single overflow channel, with its intake just below the 700-ft contour, links the valley of the Kershope Burn with that of the Bailey Water to the east. The intake [5102 8364] lies south-south-west of Golden Rocks and east of Burnt Shields and appears to have accepted marginal drainage from a glacier in the Kershope valley, discharging into Langley Burn.

LIDDEL CATCHMENT

Except for the high ground forming Lea Brae and Black Rigg, boulder clay blankets almost the entire area. Between the Liddel Water and the Back Burn there is a group of drumlins aligned parallel to the main drainage. The steeper, or stoss end of the most northerly drumlin, at Haithwaite [4435 7730], faces north-east, indicating formation by ice moving down the valley towards the south-west.

A few small mounds of sand and gravel occur near the bottom of the valley. One mound [4720 8100] along the north bank of Hagg Sike contains clayey sand, and another [4750 8170] consists of clayey gravel. Small mounds of both sand and gravel are also present south-east of Mepsy's Crook and at Hudd's Hole.

Several conspicuous sub-parallel ridges of large sandstone blocks and boulders extend for more than 1½ miles along the valley side from south-west of Stonegarthside [4740 8032] to Whiteknowe [4641 7804]. Where crossed by streams these ridges are seen to be superficial deposits, presumably part of a lateral moraine (Pl. XV).

Between ¼ and ½ mile E. of Stonegarthside accumulations of sandstone blocks and boulders form a group of five knolls, aligned approximately east–west. This debris, the provenance of which is uncertain, seems to have been dumped by melting ice, probably as a semi-fluid mass of mud and rock, and is shown as rock-moraine on Pl. XV. One of the masses appears to have collapsed and flowed downhill; it now consists of a low, elongate ridge of jumbled boulders from which all trace of the mud matrix has been weathered away.

The valley of the Carwinley Burn shows ice retreat features, but as these form an integral part of the sequence displayed in the valley of the nearby Rae Burn, their description follows below.

LYNE CATCHMENT

Red boulder clay covers much of this catchment, the erratics including a Solway suite of rocks. Drumlins are generally ill-defined but aligned east–west.

Sands and gravels are widely distributed, commonly as kames, more rarely as eskers. The Gilsland–Kirkcambeck kame-train crosses the district normal to the primary drainage direction, its course marked by kames, eskers and indeterminate mounds. North-east of Dormansteads a kame-complex consisting of two large kames (Bracken Hill and Tother Hill), several mounds and a long, low esker bounding the southern side of Pike Plantation, are associated with peat-floored lake-sites and a number of drainage channels. Farther to the north-west a low elongate sand-mass of indeterminate form stretches from Stapleton church [5034 7130] almost to the River Lyne near the suspension foot-bridge; an old quarry [4930 7190] exposes 25 ft of red, sandy gravel with a sand lens. Immediately north of Stapleton church, 4 ft of fine red sand are exposed; there appears to be little gravel thereabouts.

The Flosh, which flows westwards into the Kirk Burn, marks the site of a long flat-bottomed channel or narrow lake, now floored with peat and alluvium. It appears to have formed a temporary outlet for the Cam Beck when the lower reaches of that stream were blocked by retreating ice. At its north-western end, The Flosh was connected with one of the lakes of the Pattieshill kame-complex by means of an overflow channel south of North Greenhill, the level of the intake [5190 7068] being about 390 ft O.D. The water seems to have escaped from this lake either southwards by a channel discharging into Leaps Flosh or westwards via a branching channel passing immediately south of Dorryfield [5007 7062] and discharging into the Kirk Burn near Roweltown.

The western end of the Gilsland–Kirkcambeck kame-train is near Sunnythwaite [4567 7460], in the upper valley of the Rae Burn. A line of small sand knolls extends from Shawstown [4602 7471] to Hope's House [4650 7398], and an elongated mound of red clayey sand, with the same north-westerly alignment as the knolls, rises from the 400-ft contour to 481 ft O.D. at Thornyland [4575 7381], where it is bounded to north and south by overflow channels (H and G on Pl. XV). Owlhirst [4542 7357] is built on a roughly circular mound of sandy gravel; a small esker borders the nearby channel.

An irregular kame occurs on either side of the Hagg Beck north of Bartiestown [4730 7265]; the more westerly consists mainly of red sand and the more easterly mainly of fine sandy gravel. About ¼ mile north of Windyhill [4810 7222] a low mound of red sand with some gravel straddles a small stream.

Two extensive irregular masses of sand and gravel, probably representing englacial kames with smaller eskers, occur in the Easton area. The larger mass extends for about 1000 yd south of Hallees [4326 7222] and consists mainly of fine red sand with rare clayey lenses, but fine gravel is also present in places. The sand has been dug from an old pit 250 yd south-east of Chapeltown. The smaller, southern mass is long and narrow with an east–west alignment and a height of 20 to 25 ft at its eastern end, where it has been dug.

At Broomhills [4292 6832], 2 miles south of Easton, there are large masses of fine sand with scattered well-rounded pebbles; these deposits pass locally into gravel. On the opposite (eastern) side of the river a lens of sand, up to 10 ft thick, has been traced within the boulder clay for over a mile along the steeply sloping valley side between Southward Ford and Clinty Ford. This lens has not been found on the other side of the valley.

The drainage pattern formed by the lower part of the Rae Burn and its tributaries the Hagg Beck and Cooper's and Bell's burns, appears to have had a complex history. The pre-glacial Rae Burn probably flowed south-westward to join the Carwinley Burn. Upstream from Green Farm [4410 7340] the modern valley still follows this course, but the original continuation south-westwards from the farm is now masked by thick drift, and the river instead follows a south-easterly course towards the River Lyne. The sequence of events described below can best be followed by reference to localities lettered A to R on Pl. XV.

Ice retreating down the Rae Burn valley seems to have ponded back a series of lakes now marked by alluvial levels ranging in height from 480 ft O.D. in the north-east (A on Pl. XV) to 270 ft O.D. (L on Pl. XV) in the south-west. The lake at A seems to have been fed by drainage from the Catlowdy area via what is now a dry channel west of Mosshead [4612 7646] and by the Rae Burn, north of Birky Knowe [4734 7568]; the lake probably overflowed through a well-defined channel (B) into another lake (C) with alluvium at about 405 ft O.D. and thence to the Black Lyne.

Another well-marked channel (R) temporarily carried the flow of the Hagg Beck eastwards to the Black Lyne while the Hagg Beck valley below Haggbeck was blocked by retreating ice.

The alluvium at D (420 ft O.D.) is now drained to the west by the Hagling Burn, but the lake which gave rise to the alluvium probably overflowed south-eastwards into another lake (E, 410 ft O.D.) in the valley of the Rae Burn. From the lake at E the water at first drained south-eastwards through a channel (P) at the same level into Cooper's Burn, but at a later stage it became connected to lake F with alluvium at 360 ft O.D. and thence through a channel (G) into another lake (H) at the head of Bell's Burn (alluvium at 340 ft O.D.). At some earlier or still later stage, presumably when the easterly channel was blocked, water from lake F overflowed north-westwards via channel K (intake at 370 ft O.D.) into lake J with alluvium at 320 ft O.D., the site of which is now traversed by Yearning Sike. The latter, after being joined by the Hagling Burn, becomes the Back Burn. Lower in the Back Burn valley, a small lake (L), marked by alluvium at 270 ft O.D., was partially fed by a deep channel (M), now Draught Sike, which temporarily carried stream-flow westwards (intake at 315 ft O.D.) from the lower part of the south-westerly reach of the Rae Burn. The doubtful channel (N) north of Charlestown may not have been formed by water, but merely mark the position of the drift-filled pre-glacial valley of the Rae Burn.

BLACK LYNE CATCHMENT

In the Bailey Water valley boulder clay covers the lower ground and much of the high ground, extending locally almost up to 1000 ft O.D. on the southern slopes of Skelton Pike, but more commonly up to 800 ft. Drumlins such as those at Stoneknowe and Pattenside are aligned north–south parallel to the valley, the feature at Pattenside having its steeper end facing north. Small hillocks of sand and clayey gravel are present north of Roanstrees. Small patches of sand near Holehead [5227 7842] are probably derived from the neighbouring crags.

In the Black Lyne valley boulder clay forms an extensive cover, although well-defined landforms are rare. Sand and gravel deposits are few; between Mid Todholes [5259 7727] and a locality [5015 7655] north-east of Sleetbeck they form a train of small, scattered eskers which skirt the high ground to the south formed by the outcrop of the Oakshaw Sandstone. There is also a cluster of four small knolls spanning the river north-north-west of Dodgsontown.

A series of overflow channels near Broadside breach the spur between the valleys of the rivers Black Lyne and White Lyne. A marginal channel with its intake at about 840 ft O.D. just north of Kettle Hall [5525 8100] descends the hillside obliquely and discharges into Parkside Sike at the junction [5490 8035] with another channel entering from the south. The latter is 12 to 15 ft deep and has an 'up and down' profile typical of sub-glacial channels cut by water moving uphill under hydrostatic pressure; it crosses the topographic divide at 740 ft O.D. about 100 yd N. of Broadside thence descending into Sandy Sike, a tributary of the White Lyne, where it is joined by another, similar channel which cuts the ridge at 735 ft O.D. about 100 yd S. of Broadside.

Farther south, north of Lynestead [5470 7842] two more channels cross the divide. The northern is about 4 ft deep, but the southern is 12 to 15 ft deep, with an intake at about 590 ft O.D. and with an eastward fall into the White Lyne valley.

Still farther south, two well-defined channels breach the narrow neck of boulder clay forming the catchment divide near Slacks [5403 7777]. The northern channel passes between Slacks and Mire farms with an ill-defined intake at about 505 ft O.D.; the southern, about 300 yd S. of Slacks, has an intake about 10 ft higher. Both channels probably carried overflowing water in different directions at different times according to the relative level of ponded water in the respective river valleys on either side. An outwash fan radiating from the north-westerly mouth of the southern channel indicates flow from the White Lyne to the Black Lyne valley at a relatively late stage.

WHITE LYNE CATCHMENT

On the south-western slopes of Christianbury, the boulder clay extends up to the 1000-ft contour, but in general 800 ft O.D. is about the upper limit of the drift in the White Lyne catchment. The boulder clay is grey or chocolate-brown in colour, with Southern Uplands erratics among which boulders of Criffel Granite are particularly common. Near the Show Burn the boulder clay is bright red. Land-forms are largely indeterminate, except in the southern part of the catchment where a few well-developed drumlins conform to the regional easterly alignment.

A few small mounds of sand and gravel are associated with drainage channels in the upper White Lyne valley. The highest, at 820 ft O.D., lies just west of the junction of two channels [5567 8038] near the head of The Gill; it is about 50 yd by 30 yd across and consists of gravel with a high proportion of small boulders. Just east of the junction of The Gill with the parent river is a bifurcating ridge of sandy, clayey gravel known as Shiel Knowe [5626 7972]. Near the head of Sandy Sike are two sub-glacial channels, along which water from the Black Lyne valley is presumed to have been forced under hydrostatic pressure across the intervening divide. These channels coalesce to form a single 'downhill' channel. On the neck of ground between the two converging channels stands a small mound of sand and gravel [5516 7968], similar to the small mound at the head of The Gill, 1000 yd to north-east. The mode of origin of both mounds is obscure.

Farther south there are small sand-mounds at The Flatt [5602 7860], north-east of Raw (Brock Knowe) and alongside a dry channel south-east of Raw.

A low, sinuous esker borders the northern edge of a lake site south-west of Wellington Gate [537 764] and another forms the north bank of the river ½ mile W. of Rawney. One of two small sand hills (Cairn o' the Mount) 300 yd S.E. of Park Farm [5510 7580] appears to have been modified to form a burial mound, and several small sand patches surround The Pike [5689 7598], which caps the high ground immediately north of Bewcastle village. The village is flanked to the north by twin sandhills. The western—Hall Hills—bears traces of ancient fortification-terraces and is still occasionally quarried at the roadside for reddish purple sand and fine gravel. The eastern hill provided a convenient site for a Roman fort and later for a Norman castle, a medieval church and a 19th century rectory. On two smaller sandhills, ¼ mile to the east, one of Cromwell's generals is reputed to have sited his cannon ('Cannon Holes') when besieging the castle. To north-east, at Borderrigg, are two masses of fine, reddish sand with some gravel. The western mass is elongated along an axis a little north of west, while the more eastern, Rye Knowe, is irregular in shape.

To the south-west of Bewcastle an elongate mound of fine sand extends from the edge of the alluvium on the north bank of the River White Lyne almost to Kilnstown Farm. Next to it, on its south-western side, a small peat bog marks the site of a shallow lake. High Mossthorn [5150 7343] stands on the western end of a low, oval sand-mound, and on the south side of the White Lyne valley two small mounds of gravel, north and east of Longrigg [5075 7212], have both been worked. Up to 12 ft of gravel are exposed in an old quarry [5103 7216] in the eastern mound, where pebbles of white Criffel Granite and a pinkish granodiorite of unknown provenance have been obtained.

'Overflow' channels connecting the valleys of the Black and White Lyne have already been described (p. 254). In the valley of the White Lyne, east of Kettle Hall, two marginal channels with intakes at 900 ft O.D. [5566 8068] and 885 ft O.D. [5544 8074] respectively join [5566 8037] to form a single downhill channel now occupied by The Gill; similarly the two 'pressure' channels cutting the divide near Broadside converge south-eastward to form a downhill channel now occupied by Sandy Sike. The absence of downhill channels from the other side of the valley can probably be attributed to its west-north-westerly aspect away from the sun.

A well-defined dry channel passes north of Raw [5502 7761] and is associated with small mounds of sand; it probably carried overflow eastward from the valley of the Black Lyne to that of Bothrigg Burn.

About 400 yd W. of Crook Farm [5440 7719], a sinuous ill-defined dry channel intaking just above river terrace level (about 490 ft O.D.) passes first southwards then eastwards to Wellington Gate [5408 7643], where it is now occupied by a small stream. This channel probably marks the course of a diversion whilst the main river was temporarily blocked near Bankhead [5450 7692].

A hollow known as the Dhu Bog [5375 7582] occupies the site of a former small lake, and a larger hollow traversed by Rough Sike midway between Ann's Hill and Kilnstown now marks the site of another. Their bottom levels are about 490 and 415 ft O.D. respectively. A third lake lay ¼ mile S. of Bogside, and a fourth is now marked by an alluvial tract at the bend of the Show Burn [5520 7235] west of Winter Shields.

CAM BECK-KING WATER CATCHMENT

Except for Askerton Low Park, the Cambeck–King Water catchment is extensively covered by boulder clay which is mostly reddish, particularly where it is underlain by Permo-Triassic rocks. Drumlin-forms are well developed, especially around the headwaters of the King Water; their steeper ends, where determinable, face west.

The Gilsland–Kirkcambeck kame-train straddles both the Cam and the Knorren becks, and on the east side of Kirkcambeck village a sand-knoll has been worked. On the west side, a lens of fine sand within the boulder clay has been traced for some distance in the bank around the church. Farther south-east, on the southern edge of the district at Lees Hill, an elongate mass of red loamy sand with gravel layers has been breached by the Knorren Beck.

In Askerton Park direct overflow channels are present at various levels, the highest with intake at 620 ft O.D. A channel with intake at 590 ft O.D. south-west of Winter Shields is particularly well defined, as is another, about 1¼ miles W.S.W. of Winter Shields with intake at about 520 ft O.D. The latter is traceable for more than a mile in the direction of Parkgate Bridge, and eventually discharges into the Cam Beck via a small lake (Pl. XV).

Farther south-east, a series of overflows from the valley of Green's Burn pierce the divide to the south at levels ranging from 620 to 540 ft O.D. and discharge into the headwaters of the Knorren Beck.

IRTHING CATCHMENT

All the upland parts of the Irthing Catchment, except for the areas around The Knares and Spy Rigg, are blanketed by boulder clay and peat. The area includes Highgrains and Spadeadam wastes which are gently sloping, virtually uninhabited, upland plateaux, where east–west drumlins protrude above the level of the peat and in many cases show a marked steepening at their western ends. Along the lower Irthing valley, west of Bells Braes, many of the drumlins are aligned east-north-east parallel to the valley. Burn Divot [6940 7083], rising to 847 ft O.D. on the topographic divide between the Cumbrian and Northumbrian rivers, is a good example of a large rock-cored drumlin where the direction of ice-movement is presumed to have coincided with the strike of the solid rocks. There are no deposits of sand and gravel, and except for a single dry channel south-west of Burn Divot, there are no apparent ice-retreat phenomena. J.B.W.D.

In the upper Irthing valley in the banks of the river between Archie's Pike and Paddaburn Farm and also at Andrew's Hill [6537 7740] are several sections, each about 35 ft high, of grey boulder clay with many Scottish granites as well as local erratics. Hurtlewinter [661 788], 950 yd S.E. of Lowe Bush, is formed by massive sandstone blocks in a chaotic pile 100 by 25 yd, elongated east-south-east, and about 25 ft high. The blocks were probably transported by ice from an original rock fall. In the headwaters of the Irthing at Horse Head only local erratics are seen in the grey boulder clay.

CHIRDON BURN CATCHMENT

The highest, western part of the Chirdon catchment, on the slopes of The Knares and Black Knowe, is drift free. Elsewhere boulder clay covers most of the ground except where sandstone features protrude. Glacial striae with a general east-south-easterly trend have been noted at several localities. Near the head of Greenmeath Sike [6437 8046] striae aligned E.20°N. are partly effaced by a later set at E.30°S.; similarly, at a locality [6537 7965], 370 yd N. of Lowe Bush, striae trending at E.15°N. are crossed by a later set at E.28°S.

WHICKHOPE BURN CATCHMENT

In Back Burn valley there is little boulder clay above 1000 ft O.D., but Scottish erratics are found up the highest headwaters. For half a mile downstream from Broomylinn Farm sandy and gravelly boulder clay is exposed. Farther downstream near the confluence with Nishaw Burn [649 851] the boulder clay has a greenish tinge from the incorporation of much Middle Border Group material. In the floor of a tributary [6365 8597] between Rough Pike and Stower Hill, a sandstone shows exceptionally good striae trending E.30°S.

In the headwaters area of Binky Burn, west of Reeker Pike, no far-travelled erratics have been seen in valley sections or in the alluvial gravels: Scottish ice may not have overridden this area. Farther downstream small sections in the banks of Binky Burn show that the boulder clay becomes progressively less sandy downhill and that Scottish granite and greywacke erratics become larger and more numerous.

In the Whickhope catchment, valleys are typically asymmetric with gentle slopes of thick drift on the north and west sides, and steeper drift-free slopes on the east and south sides. A drift-filled buried valley probably underlies the north side of Back Burn for about a mile below Broomylinn Farm and the south side between Low Cranecleugh and Whickhope Lodge.

The Rigg, about ¾ mile E.S.E. of Broomylinn, is crossed by four sub-parallel valleys which drain east-south-eastwards from the crest. They are cut in boulder clay and range from 150 to 200 yd in length, though they are only a few feet deep. They are probably overflow channels which operated for only a short time during a temporary ice-damming of meltwater in the Back Burn valley. Another overflow channel trenches the hillside north of White Sike; it is floored by peat and it drains eastward from an intake [6775 8505] at 900 ft O.D.

LEWIS BURN CATCHMENT

Small areas of boulder clay are found up to 1400 ft O.D. in the headwater areas of Lishaw and Yett burns, while Scottish erratics are scattered over the highest ground. In the Lewis Burn valley much of the boulder clay has a greenish or, in places, purplish tinge from the incorporation of Middle Border Group material. Downstream from High Long House the burn has cut a gorge about 70 ft deep in boulder clay. Lishaw Linn [599 851] on Lishaw Burn is a good example, on a small scale, of post-glacial diversion: the burn deviates abruptly from a stretch where the banks are of boulder clay into a 100-yd gorge cut through massive sandstone to a depth of 25 ft. The through valley, known as Gill Hassock [616 846], which cuts across the ridge north of Gill Pike, probably functioned as a meltwater channel. Its intake is just over 1100 ft O.D. and it grades eastwards.

D.H.L., D.A.C.M.

REFERENCES

DIXON, E. E. L., MADEN, J., TROTTER, F. M., HOLLINGWORTH, S. E. and TONKS, L. H. 1926. The geology of the Carlisle, Longtown and Silloth district. *Mem. geol. Surv. Gt Br.*

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

Chapter XV

RIVER DEVELOPMENT AND RECENT DEPOSITS

RIVER DEVELOPMENT

IT IS BELIEVED that the drainage pattern of the district was initiated on an uplifted peneplain late during the Tertiary era and that by the beginning of Glacial times most river systems were well developed and similar to those of the present day. There is evidence to show that during and immediately after glaciation the valleys were filled by ice and moraine. Because this filling was incomplete or because of differential compaction, sufficient traces of the valleys remained for the original drainage pattern to become re-established, first by englacial melt-waters and eventually by rainfall run-off. Changes in the pattern have nevertheless taken place. One of these concerns the part of the River Black Lyne north of Hole of Lyne—a stretch which originally formed the headwaters of the River White Lyne, but which was diverted or captured by the River Black Lyne near Holmehead. The most important changes, however, relate to the drainage around and north of the Tyne Gap in the area now drained by the River Irthing and its tributaries north of Gilsland and the King Water north of Highstead Ash [599 692]. These changes can best be described with reference to the primary divide.

The present primary divide (Fig. 37A) between the westward drainage to the Solway Firth and the eastward drainage to the North Sea follows the crest of the Larriston Fells southwards across the Scottish Border into the Bewcastle district at Glendhu Hill [568 865]. It continues southwards and coincides with the Cumberland–Northumberland boundary between Glendhu Hill, Black Hill [571 848], Black Knowe [583 826] and Burnt Tom Crags [596 820], from where it changes direction and follows an arcuate line, first east-south-eastwards to Hobb's Hill [725 785], in the Bellingham (13) district, then south-westwards across Denton Fell towards Gilsland and across the Tyne Gap to Hallbankgate.

South of Burnt Tom Crags a well-marked secondary divide separates the catchments of Lyne and Cam Beck from those of the Irthing and King Water. From its alignment it seems likely that this secondary divide was originally the southern continuation from Burnt Tom Crags of the primary divide. South of Ash Moss [592 701] its course is more difficult to trace in the drift-covered lower ground, but there is evidence to suggest (Fig. 37B) that it crossed the King Water at Highstead Ash and the River Irthing at Upper Denton, thence to join the present divide on Denton Fell.

The present pattern of drainage suggests that the original primary divide followed an uninterrupted southward course across the Bewcastle district and that the drainage of the River Irthing north of Upper Denton and the King Water north of Highstead Ash, originally formed eastward-flowing headwaters of the River Tyne. Evidence in support of this contention is set out below.

Between Paddaburn [640 777] and Shankend [688 767] the River Irthing, in its upper reaches, flows in a wide, drift-filled semi-mature pre-glacial valley which presumably originated as a consequent stream draining the eastward-sloping plateau now forming High Grains Waste and Greyfell Common. At an early stage, it would have flowed eastwards at Shankend across the outcrop of Spy Rigg Sandstone to join with the Wark Burn and to discharge into the River North Tyne. Later it must have been captured at Shankend by the headwaters of a southwards flowing stream—now represented by the stretch of the River Irthing between Bells Braes and Shankend. This southerly stream continued from Bells Braes through a deep valley, now obscured by drift, east of Burn Divot [695 708] and High Tipalt [697 685]; it joined the present Haltwhistle Burn (now an obvious misfit) near Burnhead, where the Whin Sill forms a nick-point, and eventually discharged into the River South Tyne at Haltwhistle. This buried channel was proved ¼ mile E. of High Tipalt by a bore which encountered 113 ft of glacial drift with rockhead at about 540 ft O.D.; this is about 80 ft lower than the present level of the floor of the drift-filled adjacent stretch of the Tipalt Burn immediately north of the bore site. The pre-glacial river which formerly occupied this channel is referred to on Fig. 37B as the River Irthwhistle.

Stretches of the present Tipalt Burn, on each side of its intersection with the River Irthwhistle, probably formed subsequent tributaries of the latter. A stretch of the River Irthing, extending from Bells Braes to near Wiley Sike Farm [662 709], also formed a subsequent tributary; it was later to undergo reversal of flow direction.

Another major headwater of the South Tyne, here called the River Irthalt, flowed in the present north–south rejuvenated pre-glacial valley of the King Water between its junction with the Caud Beck [628 722] and Crying Crag [639 711, not named on the one-inch map]. Its course is believed to have continued southwards through a conjectural buried channel past Crying Crag, eastward of Round Rigg [637 702] to join the River Irthing west of Crammel Linn [641 697]. It then flowed southwards through a mature valley on the site of the present Gilsland Gorge to Irthing House [637 673] and thence eastwards through the Tyne Gap—a pre-glacial valley much modified by ice and later meltwater—to join the present course of the Tipalt Burn south of Thirlwall Castle [659 662]. Before the passage of ice eroded and deepened the Tyne Gap, the outcrop of the Whin Sill at Greenhead would probably have formed a nick-point, and the original mature course of the River Irthalt upstream of Greenhead and through the present rejuvenated Gilsland Gorge would have been graded to this former level. Trotter and Hollingworth (1932, p. 167) considered the Gilsland Gorge to be post-glacial, but incised meanders and hanging tributaries indicate rejuvenation of a formerly mature valley.

Subsequent tributaries of the River Irthalt probably included the River Irthing between Upper Denton and Gilsland (flowing eastwards), the River Irthing between Crammel Linn and Wiley Sike, the King Water between Crying Crag and Highstead Ash (flowing eastwards), and the Tipalt Burn west of Low Tipalt [684 679]. Additional evidence for local reversals of flow direction is afforded by the angle of entry subtended by the tributary streams with parent rivers (assuming that near the confluences both the major rivers and tributaries occupy their original pre-glacial courses). In almost all cases (Fig. 37) this angle is acute in the original direction of flow of the larger river.

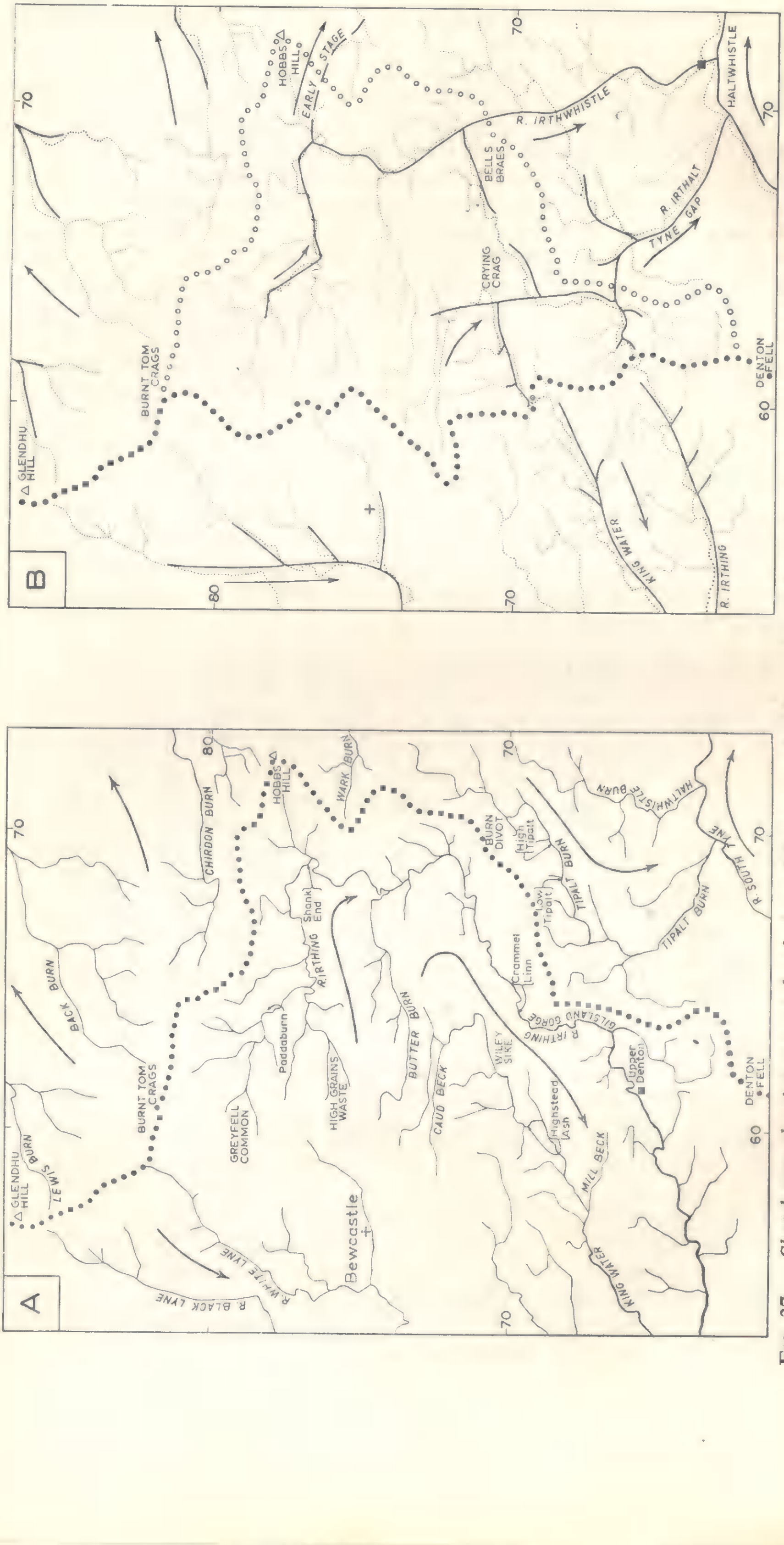


FIG. 37. *Sketch-map showing present-day drainage (A) compared with pre-glacial drainage (B) Arrows indicate direction of drainage; heavy stipple marks line of watershed*

The late- and immediate post-glacial history of the rivers near the Tyne Gap at Gilsland is complicated by the quantities of ice and later overflow water which presumably passed eastwards from glacial Lake Eden. Trotter and Hollingworth (op. cit., p. 167) postulate pre-glacial capture of the River South Tyne by a tributary of the River Irthing on the basis of an apparent westerly gradient of the supposed pre-glacial valley floor between Haltwhistle and Greenhead (rockhead was proved at 275 ft O.D. in a bore south-east of Greenhead). However, it is known that bottom ice under great pressure traversed the Tyne Gap (op. cit., p. 151) and the form of rockhead in the valley is more likely to represent overdeepening by ice than pre-glacial westerly drainage especially when the latter alternative is contrary to the other evidence pertaining to the stream development of the district.

The final diversion of the River Irthalt westwards at Gilsland is assumed to have occurred immediately after ice had retreated from the Tyne Gap and Lake Eden had subsided. Through its ice-gouged valley, the River Irthing below Gilsland was then able to capture the upstream portion of the River Irthalt, which was at that time flowing eastwards through the Tyne Gap, immediately north of Gilsland village. This capture led to intense rejuvenation of the River Irthing through Gilsland Gorge upstream as far as Crammel Linn, the present nick-point.

The function of the well-marked drift-filled connecting hollow—now the course of the Mill Beck and the site of Midgeholme Moss—between the King Water and the River Irthing remains obscure. Possibly it temporarily carried the upper Irthing drainage westwards from Gilsland to the King Water at a time when other outlets were blocked by ice or moraine.

ALLUVIUM AND RIVER TERRACES

All the larger and some of the smaller rivers within the district are flanked by modern alluvium and river terrace deposits. The lithology of the modern alluvium varies greatly. Some of the immature streams draining the steeper fell sides are subject to sudden floods and their alluvia commonly consist of torrent deposits of boulders of all sizes. By contrast the alluvium bordering the larger and more mature rivers usually consists of fine silt, although layers of rounded pebbles and platy boulders are by no means rare.

Locally up to five distinct terraces can be distinguished, but as some grade into others and few can be traced for any distance, they have not been differentiated on the one-inch map. The most extensive terrace deposits occur just within the western margin of the district at Riddings, a short distance upstream from the confluence of the Liddel Water with the River Esk. They are up to half a mile wide and occupy the whole of the ground between a wide loop of the Liddel Water and the railway. Exposures are few, but they suggest that as a general rule the coarseness of the deposit increases with height above river level.

In the valley of the River Lyne, particularly around the confluence of the rivers White Lyne and Black Lyne, three terraces can generally be distinguished at heights of 12 to 15 ft, 18 to 20 ft, and 25 to 30 ft above present river level. The flood plain alluvium is about 6 to 8 ft above normal water level. North-west of Roweltown [494 716] and east of the Suspension Foot Bridge [490 718] a small mound of glacial gravel almost borders the top edge of the highest terrace; probably the latter is contemporaneous with, or immediately post-dates, the former.

In the valley of the River Irthing, around Bells Braes, up to five terraces can be distinguished, the highest being 25 to 30 ft above river level. At the junction of the river with the Butter Burn four terraces are present and an 'island' of first and second terrace protruding through the alluvium (Plate VIIB) forms a conspicuous feature. The southern arm of the horseshoe bend in the River Irthing south-west of Lampert is actively eroding deposits of the second terrace and formation of an ox-bow lake is probable within a comparatively short time.

J.B.W.D.

PEAT

Peat is widespread throughout the district, and extends up to the highest levels. Two main types are recognized, namely hill peat and basin peat, though they are not distinguished on the one-inch map. Their separation depends not so much on difference of growth, composition and appearance but rather on their geographical setting; both types fall within the definition of bog peat as defined by Pearsall (1950, p. 65).

Hill peat forms an extensive covering to much high ground, where some element of topographic gradient and free drainage is usually present. In general, the thickness varies from 18 in to 3 ft, but locally may exceed 10 ft. The lower beds often contain many old stumps and roots of birch and pine. Specimens from near Red Sike [628 778], analysed by Dr. J. Franks, show that the lower, woody peat is Atlantic (pollen zone VIIa) and the lower part of the upper non-woody peat is Sub-Boreal (pollen zone VIIb). Under present climatic conditions, especially where the gradient increases, the peat is being actively eroded. This may be seen to best advantage on the high ground of The Knares [645 805]. Hugh Miller Jun., during the original survey, reported (in manuscript) the find of an elk's horn 870 yd S. of Hope House.

Basin peat typically occupies shallow concave hollows, basins or ill-drained areas in the old glacial land surface. The largest area is Coom Rigg Moss, on the eastern margin of the district, north-east of Muckle Samuel's Crags [7900 7950] and on the watershed between the River Irthing to the south and the Chirdon Burn to the north. It is sub-circular in form and about half a mile wide and has been the subject of detailed ecological study by Chapman (1964a, b). Information obtained from borings shows that 'there are two separate areas where the peat exceeds 7 m, two other main areas where it exceeds 5 m, and a central region of shallower peat about 2 m deep' (Chapman 1964a, p. 302). A map (op. cit., p. 301) of the peat base contours shows the presence of submerged 'ridges', one of which runs between Little Samuel's Crags [688 794] and Rottenshaw Pike [694 792], and another connects this ridge to the higher ground north of the bog. Small 'valleys' run away from these ridges, and although there are 'several lower areas or depressions completely surrounded by high ground' only at two places are there features that 'can really be called basins' (op. cit., p. 302). The peat is apparently floored for the most part by glacial drift sometimes overlain by a sandy clay in the hollows. The south-west corner of the bog is very much lower than elsewhere, and Chapman considers that this is due to peat moving along the valley bed and producing a system of deep pools. Active peat accumulation is still taking place. Pollen zones VI to VIII are represented at Coom Rigg.

Butterburn Flow [670 760] on the south side of the River Irthing is thought to be a similar type of peat bog, although here the peat area is not limited by higher ground, except locally on the west. Smaller areas of basin peat occur as follows: [661 813] 600 yd N. of Birkygrain; [649 796] 600 yd N.W. of Lowe Bush; [640 810] just S.W. of Black Knowe; [696 814] 700 yd S.E. of Bolt's Law; [634 869] ¼ mile W. of Scald Pike and [696 836] ¼ mile N.E. of Kyloe Crags. There are also many areas of basin peat on Spadeadam Waste and on Waterhead and Thirlwall commons. Bolton Fell [490 690] is an area of basin peat similar to Scaleby Moss (Godwin and others 1937) in the Brampton district. Two areas of peat bog have 'burst', or drained suddenly, leaving at their sites clastic masses of peat. These areas are Holdher Fast [around 627 798], an area of 500 × 180 yd, and the head of Nishaw Burn [around 630 855] an area of 550 × 150 yd.

In the Irthing valley below Redsike Farm, extensive flats are peat covered, the surface of the peat exhibiting a terrace-like form and varying from 12 to 15 ft above river level. Few sections are visible, but one [6453 7719] on the right bank of the River Irthing shows 6 ft of peat on alluvial sandy gravel. The lowest 1 ft of peat is silty and woody and was formed in Boreal time (pollen zones V and VI). The next 2 ft of peat are woody and are Atlantic (zone VIIa) as are the lowest layers of the uppermost non-woody peat (specimens analysed by Dr. J. Franks). Peat terraces are also present in the Chirdon Burn above Seven Linns.

D.A.C.M., D.H.L.

CALCAREOUS TUFA

An area of calcareous tufa extending over about one acre marks the position of springs rising on the line of the Bogside Fault about 550 yd S.W. of Bogside Farm. The material is soft and has been extensively burrowed by rabbits. Other small deposits of tufa from springs associated with faults occur on the north side of Chirdon Burn [6969 8041], 1400 yd E.S.E. of Hope House; in the upper reaches of Birky Grain [6549 8084], 1500 yd E.S.E. of Black Knowe; by Nishaw Burn [6375 8549] 1400 yd N.N.E. of Broomylinn; at three springs 250 to 750 yd S.W. of Broomylinn, and at seven springs [6363 8295] along the fault through Wedder Lairs. The sites of other springs are also commonly marked by small deposits of this material; rarely the deposit is deeply discoloured by iron.

J.B.W.D., D.A.C.M., D.H.L.

REFERENCES

Chapman, S. B. 1964a. The ecology of Coom Rigg Moss, Northumberland. I. Stratigraphy and present vegetation *J. Ecol.*, **52**, 299–313.

—— 1964b. The ecology of Coom Rigg Moss, Northumberland. II. The chemistry of peat profiles and the development of the bog system *J. Ecol.*, **52**, 315–32.

Godwin, H., Walker, D. and Willis, E. H. 1957. Radiocarbon dating and post glacial vegetational history. Scaleby Moss. *Proc. R. Soc. B*, **147**, 352–66.

Pearsall, W. M. 1950. *Mountains and Moorlands.* London.

Trotter, F. M. and Hollingworth, S. E. 1932. The geology of the Brampton district *Mem. geol. Surv. Gt Br.*

Chapter XVI

MINERAL PRODUCTS AND WATER SUPPLY

COAL

COAL HAS BEEN WORKED on a small scale in various parts of the district. All the seams exploited lie at or near outcrop in the Lower Carboniferous: later Coal Measures seams which are presumed to be present beneath younger rocks have not been explored.

Apart from a 12-in seam of Middle Border Group age formerly dug [512 740] near Badds, most of the workable coals in the Lower Carboniferous occur in the Upper Border and Liddesdale groups. At Oakshaw Ford a 24-in seam, a few feet above the Clattering Band, has been mined intermittently since the middle of the last century, but excessive water forced the most recent workings to close in 1949. At a slightly higher level, the Lower and Upper Netherhill coals, both less than 12 in thick, have been worked near Netherhill Farm [508 754] as well as in the Black Lyne valley [498 747]. A 14-in seam, believed by Smith (1912, p. 153) to be one of the Netherhill coals, was worked at crop [474 742] north of Haggbeck. Considerably higher in the sequence a coal, believed to correlate with the Waverley Seam of the Archerbeck Borehole (Lumsden and Wilson 1961), crops out in the banks of the Rae Burn [464 713] west of Solport Mill. Despite a reported thickness of at least 29 in, it has not been worked; its extent is likely to be limited by faults and its quality by oxidation, as evidenced by a reddening which affects the associated strata a short distance to the south.

pro ii.

In the Irthing valley a number of thin seams have been worked locally, notably a 14-in seam above the Leahill Limestone at an island [690 725] in the river east-north-east of Gavelock Hill. In the south-east corner of the district the Thirlwall Coal, up to 44 in thick, has been worked extensively from Thirlwall Colliery (Fig. 25). Smith (1912, p. 145) states that 'the coal is an excellent one for household, steam and coking purposes' but that it 'leaves a heavy dark red ash'. In the area where it is thickest, between Thirlwall Colliery and Wall Shield Colliery in the Bellingham (13) district, it has not been exploited, partly because the area is difficult of access and partly, perhaps, because of its unstable roof. The seam thins to the south and east, and is only 20 in thick in the Cairny Croft Borehole (Trotter and Hollingworth 1932, p. 200). J.B.W.D.

In the Whitehill Moor area a number of thin seams were formerly mined for local use from shallow shafts and adits. They are (1) the Seven Linns Coal, 15 to 16 in thick, dug [6811 7747] near Whitehill Farm; (2) near Yellowmire Sike [6876 7766], about 800 yd E.N.E. of Whitehill Farm, a coal said to be 18 in thick was won by shafts and adits; (3) the Throssburn Foot Coal, said to be 12 to 13 in thick, was worked about 100 yd E.S.E. of Shank End and also from the shallow Spy Pit [6897 7635] and adits on the Northumberland bank of the

Irthing farther to the east and north-east; (4) near Coal Burn [6934 7768], 1450 yd E.N.E. of Whitehill Farm; and (5) at the head of Blind Sike [6598 7833].

A coal has been dug by Padda Burn [6515 7797] below Davison's Crags. The Gair Burn Coal was worked from adits on the Cumberland bank [6284 7873] of the burn, 300 yd N. of Irthing Head.

In the Chirdon catchment several thin seams have been mined on a very limited scale from adits. They are: (1) the Seven Linns Coal, 18 in thick, won from adits on either side of Chirdon Burn at Seven Linns [6866 8027] and beneath Muckle Samuel's Crags [6827 7896]; (2) the Clocks Cleugh coals, the lower one 12 to 16 in and the upper one 18 in thick, were worked in adits along Clock's Cleugh [6839 8073 to 6856 8104] north of Hope House, and were also tried higher up the cleugh [6865 8130]; (3) Chirdon No. 1 Coal, said to be 12 in thick, was worked on the south side of Chirdon Burn [6914 8031], 810 yd E.S.E. of Hope House; (4) Chirdon No. 2 Coal was proved in two trial adits [6924 8033] on the north bank of Chirdon Burn, 910 yd E.S.E. of Hope House; (5) the Channelbush Coal, 12 in thick, was tried on the south bank of Channelbush Sike [6756 8059] 200 yd above its confluence with Black Cleugh; (6) a 12-in seam has been dug in the headwaters of Clock's Cleugh [6868 8150 and 6882 8137]; (7) the Whickhopenick Sike Coal was proved [6690 8132] in Black Cleugh.

In the Whickhope Burn catchment the most important seam is the Shilburnhaugh Coal, which crops out in the north-east corner of the district and was mined in the 19th and early 20th centuries from a number of adits (Fig. 27). The seam was in two 14-in leaves separated by 18 in of shale. As a house coal it had a good reputation; considerable reserves remain. Several seams have been worked in a small way from adits near Whickhope Burn; they are the Bull Crag Coal, said to be about 2 ft thick [6669 8616], the Whickhope Coal, thickness unknown [6813 8640], the Merlin Island Coal, said to be 2 ft thick [6827 8643], the Merlin Crags Coal probably about 1 ft thick [6835 8645], and the Grey's Crags Coal, thickness unknown [6918 8674]. About 250 yd S. of Low Cranecleugh, the coal of that name crops out [6613 8554], but only the top 15 in of the seam is visible. The Hen Sike Coal was worked from shafts and adits in two localities [6784 8536 and 6762 8513] about ⅔ mile S.W. of Whickhope Farm. A number of seams have also been worked on a small scale from adits near Little Whickhope Burn. They are the Little Whickhope Coal, less than 2 ft thick [6879 8538], the Lower Clock's Cleugh Coal at Whickhope Linn [6907 8498], and the Reeker Coal, comprising upper leaf 5 in, parting 4 in, lower leaf 14 in [6771 8276].

In the Lewis Burn catchment, the Plashetts Coal, nearly 5 ft thick, just enters the district, on the north side of the Harrett's Linn Fault north of Burnt Tom. An old adit [6273 8715] nearby marks a trial in a seam somewhat higher in the succession. D.H.L., D.A.C.M.

Thin coals within the Liddesdale Group have been worked on the English side of the Liddel Water. They include a seam cropping out [448 795] near The Pot, and the Kilnholme Coal beneath the Tombstone Limestone at Kilnholme [436 776], while a group of seams, the Penton coals, 21 to 29 in thick and believed to be equivalent to the Oakwood coals (Upper Limestone Group or Millstone Grit Series) of Northumberland, have been worked [433 772] near Penton Mill.

Productive Coal Measures do not crop out on the English side of the Border, but they are almost certainly present at depth below Upper Coal Measures south and west respectively of the Archerbeck and Hilltop faults. These measures form an easterly extension of the Canonbie Coalfield, and a series of recent boreholes on the Scottish side of the Border proved several thick coals at depths exceeding 1000 ft (Lumsden and others, 1967).

GYPSUM AND ANHYDRITE

Gypsum and anhydrite occurring within the St. Bees Shales have been mined extensively in the Brampton (18) district to the south, where their distribution has been described by Meyer (1965). The deposit has been proved to extend to within ¼ mile of the western margin of the Bewcastle district by a boring sunk for coal near Riddings in 1914. The relevant part of the log, given in full by Dixon and others (1926, pp. 98–9), is as follows:

	Thickness		Depth	
	ft	in	ft	in
Alluvium:				
Clay	8	6	8	6
St. Bees Shales:				
Red sandy marl	6	6	15	0
Red sandy marl with gypsum bands	24	0	39	0
Conglomerate		3	39	3
Sandy marl with gypsum bands	24	9	64	0
Conglomerate	4	0	68	0
Red marl	2	0	70	0
Gypsum	1	3	71	3
Red marl		3	71	6
Limestone	7	0	78	6
Gypsum	4	0	82	6
Red sandy marl	15	6	98	0
Red sandstone	7	0	105	0
Conglomerate	1	3	106	3
Upper Coal Measures	—	—	—	—

The 7-ft limestone at 78½ ft is interpreted (op. cit.) as gypsum mixed with marl. On this reading there is a 12½-ft bed of gypsum extending between 70 and 82½ ft in the bore.

More recent exploration for gypsum and anhydrite in the St. Bees Shales has been carried out within the district, in the area south-south-east of Riddings, by the British Plaster Board (Holdings) Limited, but the results of their boring programme have not yet been made available for publication.

BUILDING STONE

Few houses and farms have been built in the district during the present century. They have required only small amounts of stone and these have generally been obtained from older derelict buildings. The Carboniferous sandstones were the principal sources of building stone in former times. The Roman outpost fort at Bewcastle was built from stone which probably came from ancient quarries [562 758; 563 761] in the Earthwork and Parkhead sandstones near Crossgreens. Some larger blocks may possibly have been brought from the great crags of the Long Bar [593 805] on Whitelyne Common. Both Bew Castle and St. Cuthbert's Church were built during the reign of Edward I from stone obtained from the ruined fort, and it is possible that the sculptor of the well-known Anglian cross obtained his raw material from the same source. Dressed stone from the fort can be identified in the walls of many of the local buildings.

St. Bees Sandstone is generally considered suitable for building purposes, but the only large quarry, now disused, is at Lowshall [419 715].

SAND AND GRAVEL

Scattered deposits of sand and gravel in the form of late-glacial kames and eskers are distributed over the lower ground south and west of the Bewcastle Fells. A large part of these deposits forms a single kame-train, marking the line of a major englacial drainage system, which starts near Thornyland [458 738] and runs south-eastwards to Kirkcambeck thence across the southern margin of the district to the Tyne Gap at Greenhead. Possibly the largest concentration of sand occurs 1¾ miles N.W. of Kircambeck where two large kames forming Bracken and Tother hills, respectively 500 yd N.E. and 800 yd E.S.E. of Pattieshill Farm [509 702], are associated with several smaller mounds. Bracken Hill has an irregular outline and covers a surface area of about 41 acres, rising to a maximum height of approximately 50 ft, whilst Tother Hill (excluding an esker-like extension between Pattieshill and Dormansteads) is more compact, slightly higher, with a surface area of about 39 acres. The lower one-third of these kames consists of reddish gravel, while the upper two-thirds appear to be composed of fine, red sand.

A low esker, three-quarters of a mile long, extends over about 57 acres between Stapleton village and the River Lyne. Old quarries near its base expose gravel with well-rounded pebbles in a sandy matrix, but north of Stapleton church [503 713] and west of Gibshill [498 718] rabbit-burrows reveal fine, red sand. This esker rests on the side of a hill so that the maximum true thickness of gravels probably does not exceed 25 ft.

Further possible sources of fine, red sand are to be found at Chapeltown [433 417] in the form of a small esker and also a kame which has a maximum height of 30 ft and covers about 89 acres.

Much of the small local demand for mixed ballast is satisfied by modern alluvial gravels which are generally found banked on the lee side of river bridges after every flood. J.B.W.D.

ROAD METAL

In Kielder and Wark forests in the north-east of the district, river terrace and alluvial gravels are extensively quarried for road metal. Sandstone is also quarried for road metal ½ mile N.W. of Lowe Bush [6495 7982], at Craggy Shaw [6676 8032] and east of Hope House [6921 8066]. D.H.L., D.A.C.M.

PEAT

Both hill and basin peat cover large areas in the higher parts of the district, notably to the east of the catchment divide between the rivers Irthing and Lyne. Hill peat rarely exceeds 7 ft in thickness and is more extensive than basin peat which accumulates in boggy hollows to depths of up to 40 ft. Deep bogs, many of them still growing, abound in the south-east part of the district, especially on and around Spadeadam Waste, Whitehill Moor and Thirlwall Common; they are mostly inaccessible and entirely unexploited. On the lower ground smaller bogs are common and the peat in them is currently dug for domestic use. The largest, Bolton Fell, covers an area of more than 1 square mile and is locally more than 20 ft deep. Walton Moss, just beyond the southern margin of the district, supports a factory where the peat is dug, compressed, baled and distributed for agricultural and horticultural use. Peat is dug for domestic use near farms in the Upper Irthing and Lewis Burn valleys.

WATER SUPPLY

Much of the area west of Bewcastle village is served by a system of mains emanating from service reservoirs at Roadhead and Liddel Park, the source being a group of springs yielding 130 000 gallons per day on Crew Fell. Most of this water is collected in sink holes (p. 239) on the eastern side of the topographic divide between the Lyne and Irthing catchments, but it flows westwards underground along the fracture zone of the Antonstown Fault. The water is acid, because the spring's catchment north-east of White Preston is peat-covered (p. 63), and it undergoes pressure filtration and chlorination. The village of Bewcastle itself has a separate, piped supply from a local spring. In the more remote parts of the district farms and cottages still rely upon streams and small springs for individual supplies. There are private boreholes at Roansgreen [508 828] and Peel O'Hill [557 753], and at Wiley Sike one bore [667 716] supplies three farms.

Beds of Yoredale-type lithology may be regarded as multi-layer aquifers in which only the sandstones and limestones are potential water-bearers. As these beds are usually separated by impervious shale, each individual sandstone or limestone forms a unit aquifer with little leakage from adjacent units. Groundwater in each is likely to be confined under pressure, so that the final rest water level in a well is related to the individual pressures developed within each unit aquifer penetrated by that well. Under these conditions movement of groundwater from unit to unit within the borehole is almost certain to occur.

It is a characteristic of this type of aquifer that true equilibrium between yield and pumping water level may not be attained under test conditions, and the apparent maximum yield of a bore during test may exceed its maximum continuous yield when working.

At the Spadeadam Research Establishment, water for domestic purposes is obtained from four boreholes of between 11 and 12 inches in diameter. The details are given in the table below:

Well	Aquifer	Depth in feet	Yield in gal/hr	Drawdown in feet
No. 1 (Middle Shield)	Middle Border Group	400	4 000	140
No. 2 (Priorlancy)	Lower Border Group	400	2 600	126
No. 3 (Camp)	Upper Border Group	400	2 500	140
No. 4 (Grey Mare)	Middle Border Group	450	10 000	140

A chemical analysis of a sample taken from No. 1 Borehole yielded the following results:

	Milligrams per litre
Total dissolved solids	428
Total hardness*	288
Calcium hardness*	158
Magnesium hardness*	130
Total alkalinity*	400
Sulphate, as SO_4	13
Chloride, as Cl	7
Nitrate, as N	absent
Silicate, as SiO_2	16
Iron, as Fe	1·2
Manganese, as Mn	absent
pH value 7·6	

*Expressed as $CaCO_3$

J.B.W.D.

REFERENCES

DIXON, E. E. L., MADEN, J., TROTTER, F. M., HOLLINGWORTH, S. E. and TONKS, L. H. 1926. The geology of the Carlisle, Longtown and Silloth district. *Mem. geol. Surv. Gt Br.*

LUMSDEN, G. I. and WILSON, R. B. 1961. The stratigraphy of the Archerbeck Borehole, Canonbie, Dumfriesshire. *Bull. geol. Surv. Gt Br.*, No. 18, 1–89.

—— TULLOCH, W., DAVIES, A. and HOWELLS, M. F. 1967. The geology of the neighbourhood of Langholm. *Mem. geol. Surv. Gt Br.*

MEYER, H. O. A. 1965. Revision of the stratigraphy of the Permian evaporites and associated strata in north-western England. *Proc. Yorks. geol. Soc.*, **35**, 71–89.

SMITH, S. 1912. *Report of the committee appointed to report upon the Carboniferous Limestone formation of the North of England, with special reference to its coal resources.* Newcastle upon Tyne.

TROTTER, F. M. and HOLLINGWORTH, S. E. 1932. The geology of the Brampton district. *Mem. geol. Surv. Gt Br.*

Appendix I

SECTIONS MEASURED AT OUTCROP

Ashy Cleugh

6-in NY 57 N.E. Measured by J. B. W. Day.
Shown graphically in Fig. 8. For map see Fig. 9.

	ft.
LOWER BORDER GROUP	
BEWCASTLE BEDS	
JUNCTION LIMESTONE	
Limestone; weathering yellow; serpulid [5781 7670] ..	3 to 4
WATERFALL SANDSTONE	
Sandstone, massive [5760 7677]	8 to 10
Shale, sandy	12
Sandstone, massive	8
Shale, sandy	6
PEEL LIMESTONE	
Limestone, flaggy, algal; nests of *Serpula*, *Girvanella ducii*, *G. sp. nov.*, *Ortonella kershopensis*	3
Shale, slightly sandy	3
STACK CLEUGH OOLITE	
Limestone, flaggy; algal patches and bands of algoolite; *Garwoodia gregaria*	4
Shale	½
PLANTATION SIKE SANDSTONE	
Sandstone, massive	5
Shale; *Leiopteria* cf. *laminata* and *Modiolus*?	10
Sandstone, flaggy	2
Shale, sandy; *L. laminata*, *Modiolus sp.*, *Paraparchites sp.* and other ostracods ..	8
Limestone; small algal nodules	2
Sandstone [5752 7678] ..	2
Shale	6
Sandstone	2
Shale, very sandy	15
Sandstone, massive	8
Shale, sandy	1¼
Mudstone, calcareous, weathering yellow	¼ to ½
Siltstone; plant remains ..	1¼

	ft
RIGGHEAD LIMESTONE	
Limestone, yellow-weathering massive; in beds about 18 in thick; a band of nodular algal limestone weathering pink occurs about 18 in below the top; *Garwoodia gregaria*, *Girvanella ducii*, *G. wetheredii*, *G. oxfordensis*, *Ortonella kershopensis*, *O. tenuissima*, *Serpula sp.*, shell fragments indet. and ostracods [5734 7679]	8
Shale (succession down to Ashy Cleugh Limestone is measured in left bank) [5748 7674] ..	3 to 4
Mudstone, dark shelly	1
Decalcified bed, ochreous-weathering	½
Shale, flaggy, calcareous, cementstone ribs	2
Fireclay	¼
SANDWICH	
Algoolite, yellow-weathering hard; ostracods	1
Mudstone, nodular, algal; *Garwoodia gregaria*, *Girvanella ducii*, *Ortonella furcata*, *O. kershopensis*	¾
Limestone, algoolitic	¾
(This horizon is also exposed in the cleugh at other localities [5751 7677, 5728 7678 and 5736 7677]; see also Fig. 9)	
Shale, dark grey; rare *Modiolus latus* near top	5
Sandstone, massive and flaggy ..	3 to 4
Limestone, dark	½ to ¾
Seatearth, calcareous; pyrite nodules and thin coaly layers	½ to ⅔

	ft
Shale, dark; thin limestone ribs; *Leiopteria laminosa*, ostracods at base	16

ASHY CLEUGH LIMESTONE

	ft
Limestone, weathering yellow, non-algal; rare *Antiquatonia teres*, *Ovatia bioni* and ostracods	8
(This limestone crops out for some distance downstream until terminated by a north–south fault [5737 7680]. Its crop is repeated [5727 7674] still farther downstream, and the underlying section is measured from that locality.)	
Shales, dark at base; limy bands	7
Limestone, argillaceous; ostracods and small algal pellets in upper half	1½
Seatearth, dark brown shaly, ?calcareous	1½
Limestone, flaggy argillaceous	1½
Shale, sandy, clayey band at top	15
Shale, ochreous-weathering shelly bands	3
Shale, calcareous	2½
Limestone, hard oolitic; serpulid, *Spirorbis sp.* [5726 7675 and 5715 7677]	½
Shale, sandy	1½
Sandstone, flaggy, nodular and ?algal (stream bed)	3
Shale, sandy; sandstone ribs	8
Sandstone, flaggy	2
Shale, sandy; thin sandstone bands	7
Ochre band	¼
Shale, dark	1½
Sandstone, ochreous calcareous shelly; *Modiolus latus* and *Myalina pernoides*	¾
Shale, sandy	1½

EARTHWORK SANDSTONE

	ft
Sandstone, flaggy and massive [5705 7677]	4 to 20
Shale, sandy; bands of argillaceous sandstone; *Modiolus latus* and ostracods	10

NEW HOUSE LIMESTONE

	ft
Limestone, earthy impure; ostracodal and oolitic layers; rare small algal pellets	8
Shale, sandy, argillaceous sandstone bands; *Modiolus latus* and ostracods including *Paraparchites* near base	13
Shale, calcareous; thin bands of algal limestone	2

PARKHEAD SANDSTONE

	ft
Sandstone, massive	12
Shale, poorly exposed	10
Sandstone [5687 7676]	5
Shale, sandy	6
Sandstone, slump-bedded, massive	8
Shale, sandy	8
Sandstone, massive	10
Shale, sandy	2½
Shale, dark calcareous; ostracods include *Knoxiella* and *Paraparchites*	2
Limestone, very shaly, ooliths and inconspicuous algal nodules; *Girvanella ducii*, *Ortonella furcata*, *O. kershopensis* and *O. tenuissima*	5
Shale, sandy, fossiliferous 15 ft above base; *Euphemites sp.*, *Myalina pernoides*, *Schizodus sp.* and ostracods	20
Sandstone, flaggy	2
Shale, sandy	3

HOLMEHEAD LIMESTONE (Upper Leaf)

	ft
Limestone, earthy impure; *Serpula sp.* (near top), *Modiolus latus*, *Sanguinolites* ? and ostracods	5
Shale; cementstone ribs, rare ochreous bands; poorly exposed; bivalves abundant at base, including *Aviculopecten* aff. *plicatus*, *Myalina* cf. *pernoides*, *Modiolus* cf. *latus* and ostracods	18

HOLMEHEAD LIMESTONE (Lower Leaf)

	ft
Limestone, shaly argillaceous; *Sanguinolites sp.*	5
Shale, calcareous	7
Not exposed; some shale debris	20

KITTY BECK LIMESTONE

	ft
Limestone, brownish grey massive argillaceous; *Serpula*?, bivalve fragments indet., ostracods including *Paraparchites sp.*	12
Shale, sandy	15
Sandstone, flaggy shaly, current-bedded	15
Shale, sandy grey; plant remains	8
Sandstone, passing laterally into shale	0 to 1
Limestone, grey; rare algal nodules, *Garwoodia gregaria*, *Ortonella furcata*, *O. kershopensis*	1½
Shale, fossiliferous calcareous, yellow-weathering cementstone bands, becoming sandy towards top; fauna includes *Lingula* aff. *squamiformis*, *Retispira*?, *Euphemites sp.*, *Plagioglypta sp.*, *Aviculopecten plicatus*, *Edmondia* cf. *laminata*, *Nuculopsis* aff. *gibbosa*, *Modiolus latus*, *Sanguinolites plicatus*, *Schizodus sp.* and ostracods including *Cavellina sp.* . .	30
Not exposed; probably shale . .	4

	ft
Shale; cementstone bands . .	6
Cementstones, banded; *Aviculopecten sp.*, *Nuculopsis* aff. *gibbosa*, *Modiolus*?, *Sanguinolites*? and ostracods	2
Shale, calcareous	3
Limestone, shaly	3
Shale, calcareous	6

BOGSIDE LIMESTONE

Limestone, grey; *Antiquatonia teres*, *Composita* aff. *ambigua* and ostracods (in stream) . .	10
Limestone, grey, massive; *A. teres* common	16
Shale, calcareous; *Plagioglypta sp.*, *Euphemites sp. nov.*, *Donaldina sp.*, *Hypergonia*?, *Aviculopecten*, *Myalina* cf. *pernoides*, *Nuculopsis* aff. *gibbosa*, *Polidevcia attenuata*, *Schizodus sp.* and ostracods including *Glyptopleura sp.*	1¼
Limestone, massive; rare shaly partings; *A. teres*, *Composita* cf. *ambigua*, smooth pectinoid indet. (Stockastead Quarry) [5647 7698]	10½

Birky Cleugh

6-in NY 57 N.E. Measured by J. B. W. Day.
Shown graphically in Figs. 13 and 17. For map see Fig. 15.

LOWER BORDER GROUP

CAMBECK BEDS

BARRON'S PIKE SANDSTONE (lowest post)

	ft
Sandstone, medium-grained [5943 7542]	10

LOWER ANTIQUATONIA BAND

	ft
Shale, calcareous; thin limestones; abundant *Antiquatonia teres*	35 to 40
Limestone, shaly; flaggy bands crowded with *A. teres* [5937 7539]	25 to 28
Shale, calcareous; limestone ribs containing abundant *A. teres*, also '*Camarotoechia*' *sp.*, *Ovatia bioni*, *Schuchertella ambigua*, *Spirifer sp.*, and *Straparollus*? [5935 7539 and farther upstream beyond fault]	20
Limestone, shaly; crinoid debris, echinoid spines, *Spirorbis sp.*, trepostomatous bryozoa, '*Camarotoechia*' cf. *fawcettensis*, *Cleiothyridina glabristria*, *Schuchertella ambigua*; gastropod indet., *A. teres*, *Schizodus sp.* . .	4½ to 5

MAIN ALGAL BEDS (loc. 25)

M.A.14

Limestone, grey hard; inconspicuous algal nodules; in right bank immediately east of small fault [5932 7538] . .	¾
Shale, sandy; the uppeı part cut out by fault	4

	ft
WOODHEAD CRAG SANDSTONE	
Sandstone, medium-grained; 'curled' bedding and flaggy bands	10
Shale	2
M.A.13	
Cementstone, shaly; abundant small algal nodules 1 to 2 cm in diameter	3
Limestone, shaly serpulid; [5930 7533 and 5927 7539 repeated by fault] large compound nodular algal masses commonly encrusting orthoceratids (*Dolorthoceras*), or more rarely, bellerophontoids: algal species include *Bevocastria conglobata*, *Girvanella ducii*, *Ortonella furcata*, *O. kershopensis*; some of the larger nodules are encrusted with *Spirorbis sp.*	5
Sandstone; shale band	6 to 7
Shale; sandstone lens	8
M.A.12 ('Main Reef' of Garwood)	
Cementstone, shaly; prominent algal nodule bands and large compound algal masses commonly encrusting orthocone nautiloids (*Dolorthoceras*) [5924 7538 right bank and 5927 7538 left bank, repeated by fault]; algal species include *Bevocastria conglobata*, *Garwoodia gregaria*, *Girvanella ducii*, *G. wetheredii*, *Ortonella furcata* and *O. kershopensis*	4
Shale, sandy; rare algal nodules especially at top	5
M.A.11	
Mudstone, calcareous algoolitic; prominent algal nodules; species include *Bevocastria conglobata*, *Garwoodia gregaria*, *Girvanella ducii*, *G. wetheredii*, *Ortonella furcata* and *O. kershopensis*	2
Limestone, algoolitic; ooliths grade through pisoliths to '*Osagia*'-type nodules, *Bevocastria conglobata*, *Garwoodia gregaria*, *Girvanella wetheredii*. *G. ducii*, *G. amplifurcata*	2
Shale	⅔
Sandstone	4
Shale	¾
Limestone, hard sandy	⅔
Sandstone; subordinate shale bands	4½
Sandstone	1⅔
Mudstone, shaly, plant remains	4 to 5
Cementstone, shaly; rare small algal nodules and *Schizophoria*?, bivalve fragments and ostracods	1¼
Sandstone, flaggy	¾
ORBICULOIDEA SHALE	
Shale, partly calcareous; abundant *Orbiculoidea nitida* in band 4 ft above base, *Aviculopecten* cf. *subconoideus*, *Pteronites latus*, *Sanguinolites striatus* Hind, *Polidevcia attenuata*, *Plagioglypta prisca*, *Bellerophon sp.*, *Lingula mytilloides* (registered numbers 67827 to 67861) [5918 7538]	5½
Cementstone, shaly; *Rhabdoderma sp.* and ostracods ..	2½
Not exposed	1 to 2
M.A.10	
Cementstone, shaly nodular algal; orthocone fragment ..	2
Shale, calcareous, abundant small algal pellets; *Garwoodia gregaria*, *Girvanella ducii*, *G. spp. nov.*, *Ortonella furcata*, *O. kershopensis* and *O. tenuissima*	4
Cementstone; subordinate shale bands, algal nodules; *Aphralysia sp.*, *Garwoodia gregaria*, *Girvanella wetheredii*, *Ortonella furcata* and *O. kershopensis*	6
Sandstone, flaggy current-bedded	6 to 7
Shale; limy ribs at top; *Ovatia bioni*, *Aviculopecten sp.*, *Modiolus sp.*, *Pteronites latus*, ostracods and comminuted shell debris	12
M.A.9	
Cementstone, yellow-weathering massive sandy; rare ooliths and microfossils ..	2⅔

	ft
Cementstone, shaly; rare shell debris..	4
Cementstone, massive; microfossils and sparse small algal nodules	3
Shale, calcareous; cementstone bands and sandy ribs	9 to 10
Shale, thin sandy bands; *partly exposed*	6
M.A.8	
Cementstone, yellow-banded algal	1½
Cementstone, oolitic	½
Cementstone, massive impure; algal at top; productid fragments and ostracods ..	1
Cementstone, shaly nodular; algal, particularly on the undersides of bedding planes; *Schizodus pentlandicus* at top; *Ortonella kershopensis* at base [5910 7539]	2½
Algoolite, graded; ooliths ranging from 0·1 to 1·0 cm diameter	1
Shale, nodular algal (1 in) ..	—
Limestone, nodular; algal-banded	.. ¾
Shale, nodular algal	¼
Cementstone, algal; *Garwoodia gregaria*, *Girvanella wetheredii* and *G. sp.*	½
Sandstone, flaggy argillaceous, and sandy shale	6
Sandstone, massive current-bedded; a band of concentric-layered algal nodules preserved in calcareous sandstone 1 ft above base (M.A.7)	12
Shale, sandy; limy at base ..	7 to 8
BIRKY CLEUGH LIMESTONE	
M.A.6	
Limestone, grey massive nodular algal; sparsely oolitic; *Girvanella*? and worm borings	4
Limestone, massive; algal at top; *Girvanella staminea*, *Ortonella kershopensis* and ostracods	4¼
Limestone, shaly; sporadic algal nodules; shell debris, *Modiolus sp.* and costate productid fragments; forms waterfall [5900 7540] ..	6½
M.A.5	
Limestone, nodular algal; *Garwoodia gregaria*, *Girvanella wetheredii* and *Ortonella kershopensis*	¼
Cementstone, massive grey partially oolitic; *Garwoodia gregaria* and *Girvanella wetheredii*	1¼
Cementstone, massive yellow-weathering oolitic, *Girvanella wetheredii* and *G. sp. nov.* ..	1¾
Limestone, oolitic yellow-weathering nodular; *Girvanella ducii*, *G. wetheredii* and *G. sp. nov.*	½
Cementstone, shaly banded; *Girvanella ducii*	2
Limestone, algal; orthocone nautiloid fragments, *Garwoodia gregaria*, *Ortonella furcata* and *O. kershopensis*	½
Sandstone, calcareous; ?*Garwoodia gregaria* and *Girvanella wetheredii*	½
Cementstone, shaly [5898 7540]	1
Shale, poorly exposed; includes 3 to 4 ft of sandstone	12 to 14
M.A.4	
Algoolite, massive; algal patches, ?*Garwoodia gregaria*, *Girvanella ducii*, *G. wetheredii*, *Koninckopora sp.* and *Ortonella tenuissima* (see Pl. X, fig. 3)	1½ to 2
Cementstone	1
Shale; plant remains	1
Sandstone, flaggy	.. 3
Not exposed	12
M.A.3	
Limestone; packed with *Serpula sp.* and ostracods ..	1 to 2
Shale	5
Limestone. shaly; *Girvanella wetheredii* and *Ortonella kershopensis*	2
Shale partly obscured	3 to 4
M.A.2	
Algoolite; *Girvanella ducii*, *Ortonella kershopensis*, and *O. tenuissima* [5891 7538] ..	¾
Cementstone	1
Algoolite, shattered	1½
Shale, sandy	3 to 3½

	ft
Sandstone, flaggy	14 to 15
Shale, sandy	1
Sandstone, massive	3½
Shale, sandy	6 to 7

M.A.1

	ft
Cementstone, sandy	1½
Cementstone, oolitic; small algal nodules, orthocone nautiloid, bivalve fragments, *Girvanella wetheredii*, *G. staminea*, *Ortonella furcata* and *O. tenuissima*	1¼
Cementstone, massive sandy oolitic; in two beds, rare worm tubules	2½
Shale, calcareous	¾ to 1
Algoolite	1
Cementstone	1
Algoolite	¾
Cementstone	3
Limestone, oolitic reef-like, undulating top; abundant *Serpula advena*; also *Ortonella furcata* and *O. tenuissima* [5885 7540]	1¾

BEWCASTLE BEDS

	ft
Shale, sandy	6
Sandstone	1½
Shale, yellow-weathering; limestone ribs	6
Breccia, decalcified; weathering yellow	½
Mudstone	½
Not exposed: shale debris (at ford)	1

HIGH GRAINS SANDSTONE

	ft
Sandstone, massive fine-grained white current-bedded	30 to 35
Shale, sandy	3

BROWN BAND

	ft
Shale, brown; hematitized ostracods [5870 7539]	½
Shale, grey	½
Shale, brown soft; abundant hematitized ostracods	¼
Shale, grey; abundant ostracods and bivalves	2
Cementstone, shaly; worm-borings near top	1½
Algoolite; bands of algal nodules; serpulids at top	1¾
Cementstone; shaly at top	1¼
Shale; terminated by fault [5866 7538] cutting out about 30 ft of strata (exposed nearby in Bull Cleugh) and throwing up the Peel Limestone [5866 7536]	¼

Blackcleugh Burn

6-in NY 68 S.E. Measured by D. H. Land.

UPPER BORDER GROUP

	ft
Shale, grey; silty partings	4
Sandstone, thin-bedded fine-grained; ferruginous specks; rare shell and crinoid fragments	about 6
Not exposed	about 3
Sandstone, thick-bedded fine-grained	9
Fault	cuts out say 20
Sandstone, thin-bedded fine-grained; ferruginous specks; rare small shell fragments	6
Not exposed	about 6
Shale, grey; plant and root fragments; some coaly streaks; a 3-in carbonaceous shale near base [6528 8237]	7¼
Not exposed	about 3
Sandstone, fine-grained; thick-bedded above, thin-bedded below; slightly calcareous; rare crinoid columnals	6
Shale, grey; silty at top; plants	1¼
Coal	¼
Shale, grey; plants and roots	2
Not exposed except for 1 ft of fine-grained sandstone	about 7
Limestone, grey thin-bedded sandy; thin shaly partings; much crinoidal and some shell debris	3½
Shale, grey; lower part poorly exposed	4
Sandstone, brecciated; angular and irregular fragments of dark grey sandstone, cemented by calcite largely replaced by dolomite (for petrography see p. 218)	about 1
Shale, grey	about 5
Not exposed, fault cuts out a few feet of strata	say 10

	ft
Shale and silty shale; thin beds of sandstone	10
Shale, carbonaceous	½
Shale, grey; rooty at top, poorly exposed below	about 3
Sandstone, thin-bedded fine-grained ripple-marked slightly calcareous; ferruginous specks	9
Not exposed: strata seen in sike 30 yd to west are shale, grey, partly calcareous, a few limestones up to 1 in thick containing shell debris	about 7
Mudstone, hard grey calcareous; ostracods	½
Shale, grey calcareous; ostracods 1 in	—
Coal	2 in to ¼
Fireclay-mudstone, pale grey	1½
Shale, grey-brown silty micaceous; rare plant fragments above and shell fragments at base	4½
Clay-ironstone, pale fawn 1 in	—
Shale, grey calcareous; fossiliferous especially in middle; crinoid ossicles, *Punctospirifer scabricosta*, *Aviculopecten* cf. *plicatus*, *Myalina sp.*, *Polidevcia attenuata*, *Modiolus* cf. *latus*, *Pteronites angustatus* and *Sanguinolites* cf. *variabilis*	8¼
Limestone, argillaceous fine-grained	½
Fault, probably cuts out about	50
Shale, grey; calcareous and fossiliferous at base; turreted gastropod, *Leiopteria sp.*, *Myalina sp.*, *Polidevcia attenuata* and *Modiolus latus*	3½
Coal, includes 1½ in carbonaceous shale 4 in from base	½
Fireclay-mudstone, pale grey	½
Not exposed: shale debris	about 9

	ft
Sandstone, brown fine-grained slightly micaceous; ferruginous specks; thin-bedded and ferruginous with shale partings in lowest 3 ft	10
Carbonaceous shale; thin coaly partings	2¾
Shale, grey; plants and roots at top, ironstone nodules and silty bands in middle; lowest 12 ft poorly exposed	23
Not exposed	about 12
Siltstone, hard grey calcareous; weathering brown	¾
Shale, grey	1½
Mudstone, hard grey nodular silty calcareous	1
Not exposed	about 16
Shale, grey	2
Sandstone, brown thin-bedded fine-grained; shaly at top	17
Not exposed	about 35
Mudstone, grey	2
Not exposed	about 11
Limestone, grey brown-weathering argillaceous; a few shell fragments and ostracods	1⅔
Shale, grey; only debris seen, including coal near top	5
Sandstone, thin-bedded, fine-grained; silty shale partings in upper part [6519 8279]	16
Shale; only debris seen, including coal near top, and carbonaceous shale about 6 ft above base	about 28
Interbedded silty micaceous shales and shaly, fine-grained, micaceous sandstones	12
Not exposed	20
Shale, grey; silty and rusty-weathering in upper part, silty partings and shell debris in lower part	7½

Bothrigg Burn

6-in NY 57 N.W. Measured by J. B. W. Day.
Shown graphically in Fig. 6.

LOWER BORDER GROUP

LYNEBANK BEDS

RAWNEY LIMESTONE [5482 7598]

	ft
Cementstone, shaly; oolitic at base	4
Shale, calcareous	1
Algal nodule band (loc. 5); *Girvanella ducii*, *G. nicholsoni*, *G. wetheredii*, *Ortonella furcata*, *O. kershopensis*	¾
Cementstone, shaly	4½

	ft
Shale, sandy	⅓
Sandstone	1¾
Shale, sandy	3
Sandstone, flaggy	5
Mudstone; rare limestone ribs	18
Algoolite; microfossils and *Serpula*	1
Not exposed	1
Mudstone, calcareous; ostracods	⅔
Not exposed (includes Rawney Tuff and associated beds)	10
Mudstone, shaly	3
Shale, thin limestone bands; a bed of hard calcareous mudstone at the top has abundant ?worm tubes	10
Limestone, shaly	2
Shale, limestone ribs	14
Shale, calcareous; limestone bands; 1 ft *Myalina* bed at top	8
Not exposed	30
Shale	5
Not exposed	4
Shale, calcareous; shelly limestone ribs; *Myalina* and pustulose productids	16
Cementstone	6
Limestone; shaly at top, sandy and irony at base	8
Not exposed	5
Breccia; fragments of limestone and hard calcareous mudstone in greenish mudstone matrix (?desiccation breccia)	1
Shale, calcareous; rare thin brecciated bands	7
Cementstone, shaly	6
Shale, calcareous; rare bivalves	12
Shale and limestone in alternating bands	5
Limestone, shaly; algal growths including *Girvanella sp.* and *Ortonella sp.* at top	5
Shale, calcareous; limestone ribs	7
Shale, iron-rich	1
Shale, sandy; sandstone ribs	2
Shale; fossiliferous limestone ribs and disc-shaped nodules; plants	12
Shale, sandy; sandstone ribs	6
Sandstone, flaggy; shale partings	6
Shale, sandy; nests of *S. advena* in nodular limestone at top	7
Shale, dark	3
Sandstone, current-bedded	12
Shale, dark; limestone rib	5
Limestone, shaly, and calcareous shale; *Antiquatonia teres* and rare *Pustula sp.*	15
Shale, calcareous; thin limestone ribs and nodules; ostracods and shell debris	6
Limestone; subordinate shale bands [5458 7593]	14

Cam Beck, between the Askerton and Low Park Faults

6-in NY 56 N.W. Measured by J. B. W. Day.
Shown graphically in Fig. 17. Loc. 42.

	ft
LOWER BORDER GROUP	
CAMBECK BEDS	
Sandstone (against fault in river bed)	10
HILLEND ALGAL BAND	
Shale, pink; containing large, compound, reef-like algal masses [5415 6954]; *Garwoodia gregaria, Girvanella ducii, Ortonella furcata, O. kershopensis*; also exposed downstream [5414 6938] where *Girvanella amplifurcata* was also obtained; the algal masses are commonly encrusted with *Spirorbis sp.* and associated with *Serpula sp.*	2
Limestone, pinkish nodular algal	4
Shale	2
Sandstone	5 to 6
Not exposed; probably includes *Syringothyris* Limestone	20
Sandstone	10
Not exposed	14
Limestone, red; abundant shell debris and rare algal nodules	2
Shale, red; fossiliferous limestone ribs	12
Alternating thin bands of shale and fossiliferous limestone	6
Shale	2
Not exposed	5
Shale, red; sandy ribs	4

	ft
Not exposed	10
Sandstone	2
Not exposed	10
Limestone	¾
Not exposed	1
Limestone [5429 6955]	2
Shale, red calcareous; abundant *Schuchertella ambigua*; algal nodules at base; also *A. teres*, turreted gastropods indet., *Schizodus sp.* and ostracods including *Glyptopleura sp.*	10
Limestone, sparsely crinoidal; nodules of *Garwoodia gregaria*	1½
Shale	2
Limestone	3½
Shale	¾
Sandstone	7
Shale	2
Sandstone	2
Shale	2½
WHITERIGG SERPULA BAND	
Limestone, shelly; in thin beds	1
Not exposed	1½
Limestone, red; abundant *Serpula*	1½
Sandstone, calcareous	2
Sandstone, massive current-bedded	14
Not exposed	6
Sandstone, shelly calcareous	1
Not exposed	6
Limestone, red algal; abundant small '*Osagia*'-type nodules [5437 6955]	2
Sandstone, massive	10
Not exposed	6
?BUTT LIMESTONE	
Limestone, red; probably algal	2
Shale; limestone ribs	2
Not exposed; shale debris	12
Limestone, red and grey fine-grained porcellanous	2
Not exposed; sandy shale debris	2½
Sandstone, massive	2½
Shale	5
MAIDENWAY LIMESTONE	
Limestone, red shaly [5445 6952]	3½
Shale; crowded with small algal pellets	¾
Limestone	1¾
Shale, sandy; sandstone bands	8
Sandstone, massive	6
Not exposed; shale and sandstone debris	25 to 30
Sandstone, massive	8
Not exposed	3
Sandstone, flaggy	3
Not exposed	30
Shale, sandy	1
Sandstone and shale	9¼
Sandstone, massive [5455 6959]	18
UPPER ANTIQUATONIA BAND	
Shale, calcareous; limestone ribs crowded with *Antiquatonia teres*; *partly obscured*	15

Cam Beck, west of Parkgate Bridge

6-in NY 57 S.E. Measured by J. B. W. Day.
Shown graphically in Fig. 17.

	ft
CAMBECK BEDS	
HILLEND ALGAL BAND	
Limestone; abundant *Spirorbis*-encrusted algal nodules [5512 7042]	1
Shale: poorly exposed	2
Limestone, brownish dolomitized; shell fragments and ostracods	2½
Limestone, shaly; ostracods	1
Shale, sandy pinkish	1
Not exposed; shale debris	3
Limestone; nodular algal layer at top and rare *Spirorbis*: algae include *Garwoodia sp.*, *Girvanella ducii*, *G. nicholsoni*, *G. staminea*, *G. wetheredii*, *Ortonella furcata* and *O. kershopensis*	1½
Shale	1
Sandstone	3 to 4
Not exposed	6 to 8
SYRINGOTHYRIS LIMESTONE	
Shale, calcareous; limestone ribs containing abundant *Syringothyris exoleta*, and *Schuchertella ambigua*; also *Fenestella sp.*, *Punctospirifer scabricosta*, bivalves and *Antiquatonia teres* [5512 7037]	8

	ft
Fault, downthrow north about 75 ft partly repeating the above succession as follows:	
Sandstone, massive medium-grained [5514 7046]	10
Not exposed	18
Sandstone, pink; thin shale band [5517 7044]	7 to 8
Shale, red sandy micaceous	2
Sandstone, thin reddened shale bands	6
Not exposed; sandstone debris	8 to 10
Sandstone, faintly pink	3 to 4
Shale, sandy, micaceous; brightly reddened in layers, especially at top	2
Sandstone; yellowish or locally pink	2½
Shale, grey sandy micaceous; top 6 in brightly reddened	1
Not exposed; includes Hillend Algal Band	12
Shale	3

SYRINGOTHYRIS LIMESTONE

Limestone; *Syringothyris exoleta* and *Schuchertella ambigua*	½
Shale, calcareous	2¼
Limestone, crowded with *Syringothyris* and *Schuchertella*	¾
Shale, calcareous; limy ribs; *Antiquatonia teres*, *Syringothyris sp.*, bivalves and ostracods	28
Limestone, shaly, 'honeycomb' weathering at base	3⅔
Shale	5 to 6
Sandstone, massive	5
Shale; shelly at base	4
Limestone, crinoidal; ostracods	4½
Shale	1
Sandstone, massive	6 to 7
Not exposed	15
Shale, calcareous crinoidal	1½
Limestone	⅓
Shale, calcareous	1⅓
Limestone, shaly; layers crowded with small algal pellets [5535 7043]	3
Not exposed	1½

QUARRY SANDSTONE

Sandstone, massive	8 to 9
Sandstone, flaggy	8 to 10
Shale, sandy	5 to 6
Shale; flaggy sandstone bands; *poorly exposed*	21
Limestone	¾
Not exposed	7 to 8
Sandstone, rubbly; shale bands	1
Shale, pinkish	1½
Sandstone, massive	12
Shale; thin limestone ribs; *poorly exposed*	17 to 18
Limestone, rusty-weathering; crowded with shell debris including *Syringothyris* and *Schuchertella* (best seen in Melefarm Beck)	⅔
Shale; sandy towards top, dark at base, layers rich in ostracods	10½

BUTT LIMESTONE

Limestone and calcareous shale, crinoidal; abundant *Schuchertella* especially at top; also *Antiquatonia teres* and bivalves	14
Sandstone, flaggy	8 to 10
Shale; limestone ribs; abundant bivalves	6

MAIDENWAY LIMESTONE

Limestone, earthy grey	4
Shale, calcareous	1
Limestone, grey, shaly; well-preserved bivalves	1¾
Sandstone [5545 7040]	3
Fault	—
Shale, grey; rare fragments of *A. teres*	6
Limestone, grey	4
Not exposed	18
Limestone, earthy sandy	1½
Shale, limestone ribs	4
Sandstone, massive; thin shale bands	4
Shale, sandy	3½
Sandstone, massive	1½
Shale, sandy; sandstone ribs	4
Limestone, sandy earthy; rare crinoid and shell debris [5563 7047]	4
Shale	½
Sandstone, fine-grained hard flaggy; rubbly and rooty at top	4½
Shale, sandy; pinkish at base; layers rich in *Aviculopecten sp.* and other bivalves	4
Sandstone, hard (under road bridge)	2 to 3

Chirdon Burn

6-in NY 68 S.E. Measured by D. A. C. Mills.

	ft
UPPER BORDER GROUP	
CHIRDON NO. 2 LIMESTONE	
Limestone, argillaceous ..	17
Shale, micaceous; plant markings	2
Limestone; *Productus sp.*, echinoid spines, *Chaetetes*, *Fenestella*, carbonaceous and coaly plant fragments ..	1
Not exposed	½
Shale	3
Not exposed	2
Limestone; *Semiplanus* and *Lithostrotion sp.*	3
Shale, carbonaceous; locally coaly	½
Not exposed	10
Sandstone, siliceous fine-grained	1½
Sandstone, calcareous flaggy ..	10
Not exposed	10
Sandstone	12
Shale	4
CHIRDON NO. 1 LIMESTONE [6966 8021] (loc. 81)	
Limestone, grey sandy; bands of calcareous sandstone and shale	3
Shale	½
Limestone, dark grey sandy flaggy	3
Sandstone, shaly; locally calcareous; small brachiopods ..	4
Shale	6
Sandstone	1
Not exposed	52
Sandstone, massive fine-grained siliceous..	10
Not exposed	13
Sandstone, calcareous flaggy ..	6
Not exposed	15
Sandstone, fine-grained siliceous	10
Not exposed	25
Sandstone	1
CHIRDON NO. 2 COAL [6924 8034]	1
Not exposed	42
Sandstone	12
Shale	4
Sandstone, calcareous	6
Limestone; muddy; calcareous sandstone bands	4
Shale	4
CHIRDON NO. 1 COAL [6913 8032]	1
Sandstone; shale bands	4
Not exposed	3
Shale	10
Sandstone	12
Shale	2
Not exposed	4
Shale and mudstone	6
Not exposed	5
Shale, carbonaceous; locally coaly	3
Sandstone, shaly	3
Sandstone	4
Shale, micaceous	7
Sandstones and shales, alternating; incompletely exposed ..	40 to 50
SEVEN LINNS SANDSTONE	80 to 90

Coomsdon Burn

1-in Elsdon (8) Sheet. 6-in NT 70 S.W.
Measured by J. B. W. Day, partly after Anderson (1950).
Shown graphically in Fig. 13.

	ft
FELL SANDSTONE GROUP	
Sandstone, massive medium-grained; locally gritty; includes thin basal conglomerate containing pebbles of algal limestone	25
CEMENTSTONE GROUP	
CARTER FELL LIMESTONE	
Limestone, algal knobbly grey; yellowish at top, whitish at base	2½
Shale, greenish sandy	2
Limestone, white to cream nodular algal	2
Shale, sandy grey	1½
Limestone, nodular grey algal	1½
Sandstone, fine-grained, greenish	1
Not exposed	6
Limestone, massive sandy; yellowish at top, white below; several white layers crowded with '*Ottonosia*'-type algal	

	ft
nodules showing interior structure; rare fish scales	8
Limestone, thinly bedded, compact, grey; many '*Ottonosia*'-type algal nodules	3
Sandstone, thin-bedded shaly	4
Grit, calcareous; *Spirorbis* and *Serpula*; top 4 in crowded with crinoidal debris	1
Shale, ochreous	6
Not exposed	4
Sandstone	1
Shale	1
Limestone, earthy grey	1⅓
Shale, sandy	⅔
Nodular bed ?algal	½
Seatearth, sandy	⅔
Not exposed	10
Limestone, yellow-weathering sandy	2
Not exposed	8
Limestone, nodular	1 to 1½
Limestone, yellow-weathering; poorly fossiliferous	5 to 5½
Sandstone, massive	3
Shale, partly obscured	5

	ft
Limestone, very earthy; ?algal	1
Sandstone	¾
Shale, barren grey	5
Limestone, yellow-weathering nodular, algal	1½
Shale, grey	4
Sandstone, massive calcareous gritty current-bedded	3
Shale, sandy	1
Limestone, nodular	1¼
Shale, sandy, partly obscured	20
Limestone, yellow-weathering nodular; abundant *Serpula* in nests and encrusting nodules	4
Sandstone; calcareous at base; shale pellets	6
Shale, sandy	5
Limestone, yellow-weathering banded	2
Shale, sandy	5
Limestone, earthy barren	1¾
Sandstone	1
Shale, sandy	3
Limestone, nodular algal poorly oolitic	½
Fault	

Crew Burn

6-in NY 57 S.E. Measured by J. B. W. Day.
Shown graphically in Fig. 13.

	ft
LOWER BORDER GROUP	
MAIN ALGAL BEDS	
M.A.14	
Limestone, shelly; abundant '*Osagia*'-type nodules at base [5724 7844]	3
Not exposed	?
Sandstone, flaggy; hard siliceous bands and partings of grey sandy shale	7
Fault, trending N.N.E.; downthrow small to S.S.E. [5728 7853]	?
Shale, calcareous; thin limestone band; ostracods, crinoids, and bivalves such as *Edmondia* and *Aviculopecten*	5
Sandstone, fine-grained; jointed	2
Shale	1¾
Limestone; much calcite veining	1
Not exposed	?
Limestone, grey calcite veined crystalline; bivalves and ?scaphopods [5717 7847]	½
ORBICULOIDEA SHALE	
Shale; limy at base, sandy at top; *Orbiculoidea* (1 ft above base) crinoids, productids and bivalves	5
Limestone, grey yellow-weathering crystalline; ostracods and few bivalves	4
Not exposed	2
M.A.10	
Limestone; large compound algal nodules, orthocone nautiloids	½
Limestone, shaly; ostracods and bivalve debris	—
Sandstone, shaly flaggy micaceous	—
Limestone, grey; *Antiquatonia teres* and shell debris [5716 7852]	1
Not exposed	4½
M.A.9	
Limestone, grey; lower part crystalline; rare ostracods;	

	ft
middle part shaly, ostracods common, algal band with growths surrounding orthocones 2½ ft below top of exposure	9
Shale, dark grey; calcareous at top; ostracods	2
Shale, calcareous; thin limestone band; abundant ostracods ..	1¾
Limestone; ostracods, rare crinoids, brachiopod debris ..	⅔
Shale, grey, micaceous; rare ostracods	1
Limestone, grey sandy impure ..	½
Not exposed: some grey shale seen	6
Shale, grey sandy micaceous; containing balls of rolled flaggy micaceous muddy sandstones up to 1 ft across	3
Not exposed	3 to 4
M.A.8	
Limestone; bands of very small algal nodules at top (may not be *in situ*)	1
Limestone, dark grey hard ..	2½
Not exposed	2
Limestone, brown oolitic ..	1½
Limestone; many small algal nodules at top	1½
Not exposed	5
Sandstone, fine-grained	5
Not exposed	about 4
Shale; thin limestone bands containing fossil debris [5709 7853]	½
BIRKY CLEUGH LIMESTONE	
Limestone; small algal nodules	1
Limestone, grey fine-grained; ostracods, ?scaphopods, and brachiopod debris (forms waterfall)	10
Shale; small ?algal nodules ..	½
Cementstone, grey impure ..	2
Limestone, grey; ostracods, and small ?algal nodules in thin band at top	2½
Shale; thin cementstone bands; *Serpula* at and near top ..	3
Limestone, dark grey crystalline; shaly at top; ostracods ..	2
Shale, dark grey sandy; hard limy band	1
Shale, dark; rare bivalves ..	¼
Cementstone, grey nodular; ostracods and plant debris	½ to 1
Mudstone, grey; plant debris ..	3½
Shale, black; very planty ..	¼
Mudstone, grey rooty; sandy and micaceous at base	2
Sandstone, argillaceous flaggy; partings of sandy shale ..	5
Not exposed	about 5
M.A.4 [5702 7852]	
Limestone, oolitic	2
Limestone, mottled; microfossils..	1½
Limestone, shaly impure ..	1
Shale, black micaceous; fossil debris	¼
Shale; thin partings of sandstone and of hard pyritous limestone containing *Serpula* and *Spirorbis*?	up to 2½
Sandstone, flaggy; partings of sandy shale	1
Shale, sandy; thin sandstone bands	1¾
Shale, dark grey; ostracods and bivalves	2½
Shale; *A. teres* and bivalves ..	1¾
Shale, calcareous in part; limestone ribs; rare bivalves including pectinoid? at top	2
Not exposed (?shales)	1½
Limestone, dark grey pyritic; fucoid markings	1½
Not exposed	?
M.A.2	
Limestone; shaly in part; ostracods and oolites at top of exposure	2
Limestone, oolitic	2
Not exposed	½
Seatearth, shaly; sandstone band	2
Seatearth-sandstone	up to ¾
Sandstone, rooty	3½
Shale, grey rooty	1¼
Limestone, sandy; ostracods ..	4
Sandstone, micaceous flaggy; plant debris at base [5692 7841] ..	about 20
Shale, dark grey; bivalves and plant debris	3
Not exposed	2½
Shale; plant debris	2
M.A.1	
Limestone, grey crystalline; rare crinoid ossicles.. ..	2
Cementstone, dark grey thinly bedded; containing a dense algoolite band	3½

	ft
Limestone, oolitic; abundant *Serpula* and rare small algal nodules	1¼
Limestone, shaly thinly bedded	½

Crook Burn

6-in NY 57 N.W. Measured by R. H. Price.
Shown graphically in Figs. 8, 13 and 17.

LOWER BORDER GROUP

	ft
CAMBECK BEDS (loc. 32)	
Shale, grey sandy rubbly [5085 7857]	3
Sandstone, micaceous medium-grained; plants	4
Shale, grey sandy; thin sandstone bands at top; rare *Aviculopecten* at base	6½
UPPER ANTIQUATONIA BAND	
Alternating bands of thin limestone and dark calcareous shales; abundant *Antiquatonia teres*; other forms include fenestellids, '*Camarotoechia*' *sp.*, *Orbiculoidea nitida*, *Syringothyris exoleta*, *Plagioglypta sp.* *Aviculopecten subconoideus*, *Sanguinolites* cf. *striatus*, *S.* cf. *clavatus* and *Schizodus sp.*	45¼
Sandstone, medium-grained; calcareous band	3
Alternating bands of grey shale and limestone; sandy at top; *Orbiculoidea* 3 ft from top	4¾
Not exposed	2½
BARRON'S PIKE SANDSTONE	
Sandstone, shaly flaggy; subordinate beds of planty shale	18
Shale, sandy	7
Limestone, impure grey crinoidal; nodules of cementstone; ostracods, gastropods and microfossils	½
Sandstone, light grey; roots at top; ?worm markings	6
Not exposed	12
Limestone, fawn crystalline; crinoids and shell debris, *Ovatia bioni*	3
Not exposed	10
Sandstone, current-bedded medium-grained	13
Not exposed; sandstone debris	15
LOWER ANTIQUATONIA BAND	
Limestone; shaly partings; ostracods and crinoids	13
Alternating bands of calcareous shale and shaly limestone; *A. teres* abundant throughout; other forms include trepostomatous bryozoa, '*Camarotoechia*', *Composita*, *Orbiculoidea*, *Sanguinolites* (exposed immediately south-west of Crookburn Farm)	about 36

	ft
MAIN ALGAL BEDS (loc. 17)	
M.A.14	
Limestone, grey algal; sparsely oolitic near top, crinoidal below [5069 7854 and 5060 7846]	1
Not exposed	1
Shale, grey sandy micaceous; thin sandstone ribs	6
Sandstone, grey, rooty	—
Fault (throw very small)	
Shale, sandy	2
Limestone	⅛
Sandstone, rooty	½ to ⅔
Shale; rootlets	1
Sandstone; flaggy at base	3
Not exposed	3½
M.A.13	
Limestone, nodular; algal at top, crystalline at base; *Spirorbis*, ostracods	4
Shale	¾
Sandstone, medium-grained; rooty at top, massive at base	5
Not exposed	3
Limestone, fawn-weathering dolomitized	1¼
Shale	3
M.A.12	
Limestone, grey, nodular algal at top; *Serpula* at base	1
Not exposed	1
Sandstone	1
Not exposed	1½
Shale, sandy	5½
Sandstone; rooty at top, flaggy at base	5

	ft
Limestone, fine-grained grey; *Aviculopecten sp.*, *Sanguinolites* and ostracods	½
Sandstone, flaggy	2
Shale, calcareous; fossiliferous ..	1¼
Shale, grey; crinoids, scaphopods, rare brachiopods and *Sanguinolites sp.*	3
Limestone, grey; *Orbiculoidea nitida*, *Sanguinolites sp.* and bivalves	1½
Not exposed	1
M.A.11	
Limestone, grey; crystalline at top; *Spirorbis sp.*, bivalves and rare algal nodules ..	1
Limestone, fine-grained grey ..	⅓
Shale, dark nodular (?algal) ..	½
Limestone, fine-grained; ?algal nodules and ostracods ..	⅓
Limestone, fawn-grey ..	1½
Sandstone, hard grey rooty ..	1
Fault [5056 7844]	3
Sandstone, grey medium-grained massive current-bedded ..	8
Shale, sandy; rare plants	¾
Limestone, fine-grained grey; rare brachiopods, gastropods, bivalves and ostracods	⅓
Shale, sandy calcareous; fossiliferous	½
Shale, smooth; rare sandy partings	3
Shale, calcareous; thin limestone bands; abundant bivalves ..	⅓
Limestone, shaly; thin bands of fossiliferous calcareous shale; *Aviculopecten* cf. *subconoideus*, *Leiopteria*?, *Sanguinolites sp.* and orthocone nautiloids ..	¾
Shale, grey; sandy partings; *Aviculopecten* and other bivalves ..	1¾
ORBICULOIDEA SHALE	
Shale, dark grey calcareous; thin limestone bands; abundant *Sanguinolites* and *Orbiculoidea nitida*, *Aviculopecten* cf. *subconoideus*, *Palaeoneilo sp.*, *Polidevcia attenuata*, *Schizodus sp.*	2
M.A.10	
Limestone, fine-grained grey crystalline	5½
Not exposed	3
Limestone, crystalline ..	1
Sandstone, flaggy	1½
Not exposed	14
Shale, calcareous crinoidal ..	½
Not exposed	5
M.A.9	
Limestone, grey shaly ..	1½
Shale, sandy, and shaly sandstone	9½
M.A.8	
Limestone, fine-grained grey; algal breccia; shaly at base; *Girvanella amplifurcata* at top	2¼
Sandstone and shale	11½
Shale, grey	3¼
Limestone	¼
Not exposed	4½
M.A.7	
Algoolite; *Girvanella sp. nov. A.*	½
Sandstone, shaly flaggy; plant debris	8¼
Shale	1
BIRKY CLEUGH LIMESTONE	
Limestone, fine-grained grey crystalline; rare shale partings; bivalves and other shell debris	4½
Limestone, grey; crowded with *Serpula* and *Ortonella furcata*	up to 2
Limestone, flaggy grey ..	½
Not exposed	6
Sandstone, rooty	½
Shale, sandy	1½
Sandstone	6⅔
Shale, grey; calcareous at base ..	2¾
M.A.4	
Limestone, grey; *Bevocastria conglobata*, *Girvanella ducii*, *Koninckopora inflata*, *K. tenuiramosa*, *Ortonella furcata*, *O. kershopensis* at top, and shell debris in lower part ..	2½
Not exposed	5
Sandstone, flaggy; and sandy shale	11
M.A.3	
Limestone, grey cementstone-like; *Serpula*?, *Ortonella kershopensis* and *O. tenuissima*	1
Shale, grey planty	¼
Sandstone, micaceous flaggy ..	5½
M.A.2	
Cementstone, fawn-grey ..	2
Limestone, dark rubbly pyritous	¾
Sandstone, pyritous	2

	ft
Cementstone, fawn-grey ..	½
Shale, grey sandy	2
Limestone, grey to fawn flaggy ..	1
Not exposed	1
Sandstone, hard	1
Not exposed	4½
Limestone, grey impure; veined ..	1½
Not exposed	1
Shale, grey; limy bands, shattered and pyritous	4
Not exposed	1½
Limestone, grey crystalline; shell debris and ostracods	¾
Not exposed	1
Shale, dark grey calcareous ..	1
M.A.1	
Limestone, grey crystalline; crinoids, shell debris, *Serpula* at base	5
Limestone; *Garwoodia gregaria* and *Ortonella furcata* ..	¼
Cementstone	¼
Shale	1¼
Cementstone	¼
BEWCASTLE BEDS	
Shale, grey; sandstone partings ..	6½
Cementstone and shale; *partly obscured*	19
HIGH GRAINS SANDSTONE	
Sandstone, grey micaceous flaggy	2
Not exposed	17
Sandstone, flaggy	1½
Shale, grey	3
Not exposed	4
Shale, grey	½
Limestone, grey impure; abundant bivalves .. .. 1 in	
Shale	1½
Not exposed	8½
JUNCTION LIMESTONE	
Limestone, fine-grained crystalline; crinoids, gastropods, *Spirorbis* and other shell debris	4½
Limestone, algal-banded [5038 7842]	1
Limestone, *Spirorbis* and *Serpula* abundant at top	1
Limestone, nodular algal; thin shale bands	¾
Shale; thin cementstone bands ..	¼
Sandstone, calcareous	¼
Shale; cementstone bands ..	6¼

	ft
Not exposed	2
Sandstone, micaceous	2
Shale, sandy	6
Not exposed	2
Shale, hard grey	4
Limestone, fine-grained grey; ostracods and shell debris ..	2
Not exposed	4
Limestone, fine-grained grey; abundant *Spirorbis*	1
Cementstone, banded grey ..	2
Not exposed	35
PLANTATION SIKE SANDSTONE	
Sandstone, in alternating flaggy and more massive bands; some sandy shale	24
Sandstone, grey flaggy ..	17
Not exposed	17
RIGGHEAD LIMESTONE	
Limestone, nodular massive algal; exposed in both flanks of Routledge Burn Anticline [5032 7846 and 5022 7849]; *Bevocastria conglobata*, *Girvanella nicholsoni*, *Ortonella furcata* and *O. kershopensis*	7
Shale; thin cementstone bands ..	2
Limestone, fine-grained grey; ostracods, algal at base, *Ortonella furcata*	1½
Shale, cementstone ribs	½
Limestone, grey, algal; tufted nodules	⅓ to ½
Shale, cementstone bands; *Garwoodia gregaria*, *Ortonella furcata*, *O. kershopensis*	2½
Shale, sandy; micaceous at top; ostracods near base	8½
Cementstone, impure; ostracods	⅓
Sandstone, flaggy; plant impressions	¼
Shale, sandy micaceous	4½
Sandstone, grey to white flaggy ..	9
Shale, grey	2
ASHY CLEUGH LIMESTONE	
Limestone, fine-grained grey; rare *Serpula* and *Girvanella ducii*, *G. nicholsoni*, *Ortonella furcata*	2
Not exposed	3
Shale	2
Limestone, fine-grained grey ..	½
Shale, limestone partings	⅓

	ft
Limestone, fine-grained grey nodular algal; ostracods at base; *Aphralysia sp.*, *Bevocastria conglobata*, *Girvanella ducii*, *G. wetheredii*, *Ortonella furcata*, *O. kershopensis*	2½
Not exposed	5
Cementstone, grey; shale partings; *Girvanella ducii*, *G. nicholsoni*, *Ortonella furcata*, *O. kershopensis*	1
Shale, grey; calcareous at base	1
Limestone, fine-grained grey; rare bivalves and ostracods	⅓
Shale, grey; limestone partings	¼
Limestone, nodular grey algal; *Serpula*	½
Limestone, shaly algal	1¼
Limestone, fine-grained grey crystalline nodular; rare ostracods and *Girvanella nicholsoni*, *Ortonella furcata*	3
Shale, grey sandy	1
Cementstone, dark grey	¼
Shale, grey sandy micaceous	2

Ellery Sike and River White Lyne near Nixonstown

6-in NY 57 N.W. Measured by J. B. W. Day.
Shown graphically in Fig. 6.

LOWER BORDER GROUP

Lynebank Beds

	ft
Limestone [5482 7550]	4
Shale	6
Limestone	3½
Not exposed	3
Limestone, shaly	1½
Not exposed	3
Shale	6
Not exposed	16

RAWNEY LIMESTONE

	ft
Limestone, shaly	9
Shale	10
Limestone, shaly, shale bands	20
Shale	18
Shale, limestone bands	24
Limestone, shaly	2
Shale, thin limestone bands	50
Shale, limestone ribs crowded with bivalves	18
Limestone	7
Shale and thin limestones	7
Shale	7
Limestone, cherty; rare algal nodules near base	6
Limestone, massive; shale partings; algal festoon structures [5457 7567; right bank]	5
Alternating bands of limestone and shale	25
Sandstone, flaggy	12
Sandstone, massive fine-grained hard greyish current-bedded and slightly calcareous	35
Shale, thin crinoidal limestone ribs; abundant bivalves, ostracods and rare *Orbiculoidea sp.*	10
Limestone, shaly crinoidal	3
Shale, abundant *Myalina sp.*	2
Mudstone, sandy; ironstone concretions	3¾
Shaly nodule bed	½
Limestone; *Serpula advena*	½
Shale, calcareous; limestone bands; shell debris including *Schizodus sp.*	7
Not exposed	14
Shale, dark; limy ribs	8
Limestone, fine-grained dark grey; disturbed; *Serpula advena*	5
Shale, disturbed	7
Limestone, veined, algal; *Girvanella nicholsoni*, *Ortonella furcata* and *O. kershopensis*	3
Mudstone, sandy micaceous grey; rare plant debris	60
Shale, dark grey; limestone ribs; *Orbiculoidea nitida*, *Nuculopsis* cf. *gibbosa*, *Sanguinolites sp.*, ostracods	30

ELLERY SIKE LIMESTONE

	ft
Limestone, dark grey; subordinate shale bands and algal layers; *Athyris concentrica* common 10 ft above base; *Pustula interrupta* on single bedding plane 5 ft below top [5446 7583]. Algae include *Bevocastria conglobata*, *Coe-*	

	ft
losporella wetheredii, *Garwoodia gregaria*, *Girvanella staminea*, *G. wetheredii* and *Ortonella furcata*	28
Not exposed	3
Limestone, dark, and calcareous shale	2½
Limestone, dark; abundant *S. advena*	1½
Shale, sandy	8
Sandstone, massive	3
Not exposed (calcareous shale and shaly limestone at this horizon in River White Lyne)	30
Shale, dark	2
Limestone; shale band; *Ortonella furcata* and *O. kershopensis*	2
Shale, sandy; flaggy bands	12
Sandstone, fine- to medium-grained	12
Shale; limestone ribs; rare ?algal nodules	20
Limestone, dark; abundant serpulids and rare *Ortonella furcata*	1
Shale; bivalves	3
Limestone; algal nodules up to 10 cm diameter and including *Aphralysia carbonaria*, *Bevocastria conglobata*, *Garwoodia gregaria*, *Ortonella furcata*, *O. kershopensis*	1½
Not exposed	15
Limestone, shaly grey; rare *Antiquatonia teres*	28
Not exposed	10
Sandstone, flaggy	10 +

Keld Sike

6-in NY 58 S.W. Measured by R. H. Price.

	ft
LOWER BORDER GROUP	
BEWCASTLE BEDS	
Limestone, grey fine-grained [5265 8479]	1
Not exposed	1
Limestone, shaly dark blue ?cherty	¼
Limestone, fine grey; black, concentric algal nodules	1
Shale, grey calcareous; small concretions	1
Shale, micaceous; plant debris	1¼
Sandstone, greenish grey rooty	¼
Shale, grey	2¼
Shale, calcareous grey, speckled brown	1
Limestone, fine grey earthy	1¼
Not exposed, probably fault down to south-east	6 to 10
Sandstone, pale grey medium-grained [5262 8480]	4
Shale, grey partly calcareous	6
Limestone, grey earthy; small crystalline pockets; rare brachiopods	½
Shale, calcareous; bands of limestone nodules; rare productids	6
Shale, grey	3
Shale, grey calcareous; limestone nodules	1½
Shale, grey; sandy bands	1
Fault, throw small down to south-east	
Shale, grey, sandy, thin sandstone bands	2
Sandstone, whitish, brown-weathering current-bedded soft	15
Shale, grey	2
Shale, very contorted [?small fault]	1
Sandstone, brown-weathering calcareous; rare brachiopods	4
Not exposed	5 to 6
Shale, blue-grey rotten	1
Not exposed	3
Limestone, blue-grey earthy	½
Shale, grey; rare fossils	½
Limestone; abundant *Antiquatonia teres* (loc. 7) 1 in	—
Shale, soft dark grey calcareous	½
Shale, grey	1¼
Shale, grey calcareous; large limestone nodules	1¼
Limestone, fine grey earthy brown-weathering; crinoid debris and shell fragments at top [5261 8481]	1
Not exposed	3
Limestone brown-weathering fine-grained	1
Not exposed	3
Sandstone, pale grey medium-grained current-bedded; merg-	

	ft
ing upwards into fine massive sandstone	8
Sandstone, pale grey rooty	¾
Shale, grey sandy micaceous	1
Not exposed; traces of limestone and shale	?—
Sandstone, medium-grained	1
Shale, grey	⅓
Sandstone, brown-weathering, partly micaceous	¾
Shale, black carbonaceous 1-in	—
Shale, grey; plant debris	1¼
Not exposed	1 to 2
Shale, brownish grey, sandy micaceous	1
Rottenstone, weathering brown, thin shale bands	5
Limestone, fine, brown [5258 8484]	1
Shale, brown-weathering, sandy calcareous	1
Sandstone, calcareous; brachiopods 3 to 4 in	¼
Shale, grey sandy	1¼
Shale, dark grey calcareous; fossiliferous nests	1¼
Not exposed	about 6
Limestone, fine brown; black markings [5257 8485]	2½
Shale, grey	1¼
Limestone, fine brown; black markings	1
Shale, grey	¼
Sandstone, brown-weathering, calcareous; crinoids and shell-casts	3
Shale, grey sandy; rare fossils	2½
Limestone, blue-grey crystalline; productids	½
Shale, grey calcareous; fossiliferous	1

Kirk Beck, west of Bewcastle

6-in NY 57 S.E. Measured by J. B. W. Day.
Shown graphically in Figs. 6 and 8.

	ft
BEWCASTLE BEDS	
Shale [5638 7446]	1
Not exposed	6 to 8
HENNEL CLEUGH SANDSTONE	
Sandstone, massive	6
Sandstone, flaggy micaceous	5
Not exposed	23
ASHY CLEUGH LIMESTONE	
Limestone, grey; cementstone bands	5 to 6
Not exposed	7
Shale, calcareous	3
Limestone, shaly; *Serpula* and ostracods	1
Shale, sandy, grading down into seatclay at base	6 to 7
Limestone	2
Sandstone; dip apparently steep	4
Not exposed	30
NEW HOUSE LIMESTONE	
Limestone, grey [5620 7453]	3
Limestone; *Serpula* 1-in	—
Limestone; microfossils	⅓
Algoolite	½
Limestone, grey, grading into cementstone at base	6
Shale, sandy	4
Shale, dark calcareous	½
PARKHEAD SANDSTONE	
Sandstone, medium-grained current-bedded; shale band near middle (for petrography see p. 212).	15
Shale, sandy; carbonaceous partings	1
Sandstone	2
Shale, *poorly exposed*	18
Limestone, compact, grey, rare shaly bands	4 to 5
Not exposed; probably shale	20
Limestone, shaly	3
Not exposed	30
Limestone, dark grey	6 to 7
Not exposed	22
KITTY BECK LIMESTONE	
Limestone, grey blocky; ostracods [5595 7445]	15
Shale	1
Not exposed	10
Shale, calcareous	1
Not exposed	38
Sandstone, massive fine-grained current-bedded (for petrography see p. 212)	20

	ft
Shale, limy	2
Not exposed	2
Limestone, grey; alga-encrusted bivalves and inconspicuous algal nodules	2½
Not exposed	20
Limestone, fine-grained dark compact	3
Not exposed	17

BOGSIDE LIMESTONE

	ft
Limestone, shaly [5560 7347]	22
Limestone, grey; abundant *Antiquatonia teres* in top 6 ft	30

Lynebank Beds

	ft
Not exposed	4
Limestone; shelly at base	6
Sandstone, flaggy; subordinate shale, *poorly exposed*	25
Sandstone, massive (forms waterfall)	8
Limestone	5
Not exposed	2
Limestone (affected by minor fault)	6
Not exposed	15
Shale, calcareous; limestone ribs	3
Limestone; *Antiquatonia teres*	11
Not exposed	30
Limestone, massive bedded; abundant *Antiquatonia teres*	12
Limestone, shaly	10
Fault (50 yd N.W. Bogside Farm)	cutting out 90 to 100
Alternating bands of laminated limestone and shale; shell debris	8
Limestone, shaly laminated; *Myalina sp.* at base	3
Shale, grey; limestone ribs at base	12
Cementstone, shaly; *Serpula advena* near base	10
Shale	6
Shale, dark; nest of *Serpula advena*; ostracods at base	3
Cementstone, shaly	9
Sandstone, medium-grained grey	1
Not exposed	4
Limestone, shelly; *Myalina sp.* and *Polidevcia sp.*	¼
Shale, dark calcareous; crowded with ostracods and bivalves	1½
Limestone, shaly	3
Not exposed	14
Limestone, shaly dark	5
Shale	⅔
Alternations of shale and thin limestone	11
Shale, fine-grained grey calcareous	6

COMMON FLAT LIMESTONE

	ft
Limestone, thin-bedded shaly; *Spirorbis sp.* 12 ft above base (south of Common Flat Farm)	30
Alternating thin bands of shale and limestone	15
Limestone; rare spines of *Antiquatonia teres*	2

Section continues downwards in River White Lyne (p. 24).

Liddel Water, west of Penton Bridge

6-in NY 47 N.W. Measured by R. H. Price.
Shown graphically in Fig. 28. For map see Fig. 29.

Upper Liddesdale Group

	ft
Sandstone, fine-grained hard massively-bedded [4303 7739]	20
Sandstone and sandy shale	4
Shale, sandy; sandstone ribs	6
Mudstone, sandy; rare ironstone nodules and bands; *Rugosochonetes speciosus* and *Schellwienella sp.*	14½
Mudstone, calcareous; bryozoa, brachiopods, bivalves and trilobite fragments	½
Limestone, hard grey fine-grained and crystalline; *Saccamminopsis fusulinaformis* [abundant in patches] and crinoid columnals	5
Mudstone, grey silty	28
Mudstone, calcareous, silty; *Fenestella sp.* and brachiopods	2

HARELAWHILL LIMESTONE

	ft
Limestone, banded shaly argillaceous; *Fenestella sp.*, brachiopods, bivalves and trilobite glabella	3
Limestone; subordinate shale bands; nodular chert; *Lithostrotion junceum*, *Fenestella sp.*, productids and bivalves	31½

	ft
Coal 7 in	½
Sandstone, very hard fine-grained grey rooty	4¾
Sandstone, fine-grained hard grey; rare rootlets	7½
Mudstone, grey sandy	1
Coal ½ in	–
Sandstone, very hard fine-grained white rooty	1¼
GASTROPOD LIMESTONE	
Limestone, hard grey fine-grained crystalline crinoidal; rare shaly bands especially at base containing trepostomatous bryozoan fragment, brachiopods, gastropods and bivalves	21½
Sandstone, hard	½
Shale, carbonaceous 1 in ..	–
Coal 1½ in	–
Sandstone, fine-grained hard rooty	2
Sandstone, fine-grained grey; black rootlets	8
Sandstone, grey shaly	½
Coal	¼
Ganister, very hard white rooty ..	1⅔
Sandstone, grey rooty	1½
Sandstone, greenish soft shaly ..	1¼
Sandstone; irony at top and bottom	6
Shale, grey	1
Coal	½
Sandstone, hard, irony, rooty ..	½
Fireclay, light grey	2¼
Mudstone, calcareous; ironstone band; corals, bryozoa, brachiopods, gastropods, bivalves and *Beyrichoceratoides truncatus*? ..	5½
Limestone, fine-grained hard crystalline; irony at top; clisiophyllid indet., *Lithostrotion pauciradiale*, crinoid columnals, latissimoid productid fragment, and *Naticopsis variata* ..	4
Sandstone, thin-bedded pyritous	7
Sandstone and sandy shale ..	5
Shale, grey; ironstone nodules and band; crinoidal at base; corals, brachiopods, gastropods and bivalves	22⅔
TOMBSTONE LIMESTONE	
Limestone, dark grey fine-grained crystalline; in six beds separated by shale partings; brachiopods and *Euphemites sp.*	10
Shale, calcareous; fossils as above	⅔
Limestone, dark earthy; fossils as above	4
Coal	⅔
Seatearth, leached calcareous; plant roots, productid fragments, *Spirifer sp.* and pectinoid fragments	2½
Coal	¼
Fireclay, light grey soft rooty ..	3
Fireclay, dark grey rooty micaceous, ironstone nodules ..	1¼
Shale, carbonaceous	1¾
Coal	½
Sandstone, hard fine-grained white; rubbly at base	4
Sandstone, soft clayey rooty ..	1⅔
Fireclay-mudstone	2
Shale, sandy; ironstone nodules ..	¾
Shale, grey	2½
Mudstone, sandy; sandstone ribs	1¾
Shale, grey; ironstone nodules and bands	2¾
LINNS LIMESTONE	
Limestone, fine-grained hard grey crystalline; dolomitic towards top, sandy at base; crinoid columnals, productid fragments and *Pernopecten sp.*	13¾
RHYNCHONELLID SANDSTONE	
Sandstone; hard and grey at top, brownish and rooty at base; '*Camarotoechia*'? fragments	2⅔
Sandstone, rooty, and sandy shale	1⅔
Shale, black carbonaceous sandy 1 in	–
Sandstone; rooty at top, shale bands towards base	8
Shale, dark grey	3
Sandstone, greenish yellow ..	5½
Mudstone, micaceous sandy ..	¼
Sandstone, fine-grained hard rooty	2⅔
Shale, grey	1¾
Sandstone, fine-grained hard white; probably decalcified; rare rootlets; *Mourlonia griffithi*, *Leiopteria sp.*, *Myalina*? and pectinoid fragments	2½
Coal 1½ in	–
Fireclay, hard grey sandy ..	2¼
Alternating thin bands of hard micaceous rooty, clayey sand-	

	ft
stone and soft grey, rooty fireclay	2⅔
Not exposed; ?coal	½
Sandstone, false-bedded; rooty at top, (for petrography see p. 219)	29¼
Shale, grey calcareous; ironstone nodules; brachiopods, bivalves, orthocone nautiloid fragments and trilobite pygidium	6½
BRIDGE LIMESTONE	
Limestone, hard, grey, shaly at top and base; *Lithostrotion pauciradiale*, *Gigantoproductus sp. giganteus* group, *Semiplanus* cf. *latissimus*, *Rhipidomella sp.*, *Naticopsis sp.*, *Edmondia unioniformis*	20½
Coal	¼
Fireclay, grey; ironstone nodules	1¼
Shale, calcareous, and shaly limestone	5
Coal	¼
Sandstone, soft clayey rooty	2¾
Sandstone, grey, speckled brown, fine-grained hard micaceous	10½
Sandstone, grey thinly bedded shaly	20½
Shale, dark grey sandy; irony bands	3
Mudstone, soft grey calcareous; ironstone nodules and bands; *Dibunophyllum* cf. *bourtonense*, *Microptychis*? *Pseudozygopleura* cf. *rugifera*	5½
PENTON LIMESTONE	
Limestone, grey; mostly crystalline; shaly bands; algal (girvanellid?) patches, corals, brachiopods and bivalves	22

Little Whickhope Burn (S.W. of Kyloe Fault) and Reeker Sike (loc. 89)

6-in NY 68 S.E. Measured by D. H. Land.

	ft
UPPER BORDER GROUP	
Mudstone, grey silty micaceous; plants and roots in upper part; a 3-in fine-grained rooty sandstone in middle	2
Sandstone, flaggy fine-grained micaceous; many very thin shale partings	about 5
WHICKHOPENICK SIKE COAL [6759 8255]	½
Shale, grey, rooty	1
Not exposed	about 5
Mudstone, grey, micaceous	3
Sandstone, fine-grained, rare ripple-marked bedding planes	3
Not exposed	about 33
Shale, grey, rare coaly partings in upper part; brown, silty in lower part, *poorly exposed*	10
Sandstone, fine-grained	½
Shale, carbonaceous; thin coal partings	1½
Shale, grey	4
REEKER COAL [6771 8277]	
Coal 5 in	
Shale 4 in	
Coal 14 in	about 2
Shale, grey, micaceous; ironstone bands near base; rooty at top	7
Shale, grey silty micaceous; many thin partings of shaly sandstone; ironstone bands near top	10
Not exposed	about 4
Shale, grey, *poorly exposed*	about 10
Sandstone, very shaly fine-grained micaceous; silty shale partings	6
Shale, grey, *poorly exposed*	about 18
Not exposed	3
Shale, grey; silty beds	7
Not exposed	7
Sandstone, grey brown-weathering thin-bedded partly false-bedded fine- to medium-grained; rare thin shaly sandstone partings	about 40
CHRISTY'S WALLS COAL [6826 8298]	¾
Shale, grey partly carbonaceous; *poorly exposed*; some coal debris weathering out	about 8
Not exposed; rare exposures of weathered shale	about 12
Sandstone, grey, brown-weathering, fine-grained; shaly sandstone partings	6
Not exposed	about 4
Mudstone, grey silty; sandstone partings near top	4½

	ft
Not exposed	about 6
Shale, grey silty micaceous; plant fragments; a 1-ft sandstone near base	6¾
Not exposed	about 8
Shale, grey micaceous; silty at top	8
Coal; rather shaly in middle [6845 8315]	¾
Fireclay-mudstone, grey	1
Shale, grey silty micaceous; thin sandstone partings; plant fragments	2
Sandstone, mainly thin-bedded fine-grained; shaly partings; fragmentary plants	about 15
Sandstone, flaggy fine-grained; shaly at top	about 25
Limestone, thin-bedded fine-grained; thinly-laminated silty, micaceous and carbonaceous partings; rare quartz and feldspar grains, much shell debris; crinoid columnals and foraminifera (slice E 32781) [6853 8325]	1½
Coal	½
Fireclay-mudstone, grey ..	½
Shale, grey; plants and roots ..	4
Not exposed	about 5
Sandstone, fine-grained; partly calcareous	2
Shale, grey, thin sandstone partings	about 6
Sandstone, grey brown-weathering, fine-grained shaly partings near the top	2½
Mudstone, grey silty micaceous	1¼
Not exposed .. between	10 and 20
Sandstone, fine-grained ..	5
Not exposed	about 2½
Shale, grey; 4-inch bed, hard, calcareous, crowded with *Naiadites crassus* and with *Naticopsis sp.* [6869 8345]	about 4⅓
Not exposed: shale and coal debris	3
Sandstone, thin-bedded fine-grained; flaggy at base	4
Not exposed	8
Sandstone, thin-bedded fine-grained	3
Not exposed; some shale with a thin coal poorly exposed ..	about 9
Sandstone, fine-grained, massive at top, thin-bedded below (top of large waterfall)	18
Shale, grey, silty; plants	2

	ft
Sandstone, fine-grained (lowest horizon seen in Little Whickhope Burn, adjacent to Kyloe Fault [6882 8363])	4
Not exposed	about 55
Shale, grey, silty and very thin sandstone partings (in Reeker Sike) [6727 8273]	about 5
Not exposed	about 10
Sandstone, thin-bedded, fine-grained (thickens locally S.W. of Reeker Pike Fault to about 50 ft) in Reeker Sike	20
Shale, grey, silty partings; lower part poorly exposed	3
Sandstone, grey, thin-bedded, fine-grained, calcareous	2
Not exposed	about 10
REEKER LIMESTONE	
Limestone, dark grey very argillaceous; silty towards base; '*Camarotoechia*' *sp.* and *Productus* cf. *garwoodi*; [6719 8273]	2½
Shale, grey silty calcareous ..	1
Not exposed	about 14
Shale, *poorly exposed*	4
Limestone, blue brown-weathering hard argillaceous; '*Camarotoechia*' *sp.*, *Bellerophon sp.*, *Aviculopecten sp.*, *Leiopteria sp.*, *Myalina* cf. *pernoides*, *Naiadites crassus*, *Polidevcia attenuata*, *Sanguinolites sp.*, orthocone nautiloid and ostracods [6693 8267]	1
Not exposed	12
Shale, grey; carbonaceous at base	½
Fireclay-mudstone, grey	1½
Sandstone, flaggy fine-grained ..	3
Shale, grey; carbonaceous at base	3¼
Shale, grey decalcified; poorly-preserved crinoid columnals, brachiopods and bivalves ..	⅓
Shale, carbonaceous; coaly at base	¼
Fireclay-mudstone, pale grey ..	1
Mudstone, grey; small ironstone nodules in upper part and a median 3-in ironstone	4½
Sandstone, thin-bedded fine-grained micaceous; shale bands and partings [6685 8261]; represented by 6 ft of sandy calcareous flags farther to north-east [6704 8265]	4¼

	ft
Mudstone, grey; small ironstone nodules	4
Sandstone, shaly fine-grained micaceous ferruginous	½
Shale, grey; plants and roots; carbonaceous in lowest 4 in	5⅔
Coal	⅓
Shale, grey carbonaceous; thin coaly partings; plants and roots	2
Sandstone blue, brown-weathering thin-bedded fine-grained argillaceous calcareous	3
Shale; carbonaceous streaks; *poorly exposed*	about 5
Sandstone, flaggy fine-grained calcareous; *Productus* cf. *garwoodi* and *Myalina* cf. *pernoides*	1
Shale, silty; *poorly exposed*	about 3

River Black Lyne, S.E. of Holmehead Farm

6-in NY 57 N.W. Measured by R. H. Price.
Shown graphically in Figs. 6 and 8.

LOWER BORDER GROUP

BEWCASTLE BEDS

	ft
Small Fault [5399 7818]	
PARKHEAD SANDSTONE	
Sandstone, medium-grained current-bedded	6
Shale, grey sandy and shaly sandstone [5402 7819]	10
Not exposed	3
Shale, dark	1¼
Limestone, fine grey; rare ostracods	2¼
Shale, dark; limy bands; crinoid debris, *Aviculopecten sp.* and fragments of other shells	2
Limestone; bivalve debris; traces of *Girvanella wetheredii* and *Ortonella furcata*	¼
Shale, grey sandy	2½
Limestone, unfossiliferous	¼
Alternating bands of fine limestone and limy shale	2¼
Shale, dark; bivalves, including *Aviculopecten sp.* and ostracods	2½
Shale, dark; thin limestone bands; large ostracods	4
Limestone, fine-grained	½
Shale, dark grey	1⅓
Limestone, grey shaly; rare *Antiquatonia teres* and bivalve debris	1½
Limestone, blue-grey crystalline	1½
Shale, grey; limestone bands	7
Limestone, fine grey; rare ostracods	1¾
Shale, dark	1
Limestone, fine grey; rare ostracods	½
Shale, dark; bivalve debris	1
Limestone	¼
Shale, dark; layers containing abundant small bivalves	6
Limestone, shaly at base; crinoids, productids, bivalve debris and rare *Girvanella nicholsoni*, *G. wetheredii* and *O. furcata* (loc. 9c)	2½
Shale, calcareous; productid spines	1½
Limestone; rare ostracods	¼
Shale, dark grey	1½
Limestone, fine grey; rare ostracods	2¼
Shale, dark; thin bands of cementstone	6
Cementstone, grey	1
Shale, dark grey; productid spines	2½
HOLMEHEAD LIMESTONE [5406 7820]	
Limestone, blue-grey; thin shaly partings and bands; abundant *A. teres*; quartz veins at base	32
Shale, dark calcareous; thin bands of limestone	13½
Limestone, dark; shale partings; ostracods	7½
Fault, cutting out	15 to 20
Shale, dark grey sandy micaceous [5407 7820]	½
Sandstone, brown medium-grained; shaly bands	10
Sandstone, grey very shaly flaggy; shale partings	4
Not exposed; shale debris	2½
KITTY BECK LIMESTONE	
Limestone, grey massive; flaggy at base; rhynchonelloids and abundant *A. teres*: beyond a fault upstream algae include *Gymnocodium sp. nov.*, *Orto-*	

	ft
nella furcata and *O. kershopensis*	6
Limestone, grey, sandy at top, thin shale partings	5
Sandstone, grey flaggy; thin shale partings	6
Limestone, grey; microfossils	¾
Sandstone, grey medium-grained micaceous; rooty at base, flaggy at top	4¾
Shale, grey sandy micaceous	2½
Shale, dark; thin limestone bands; bivalves at base; beds disturbed in north bank	6
Shale, rubbly, disturbed along strike	3
Shale, thin limestone bands, shattered and veined at base	6
Limestone, algoolitic; *Bevocastria conglobata*, *Girvanella ducii*, *G. wetheredii*, and *Ortonella furcata*	⅓
Shale, dark grey; limestone bands	7½
Alternating bands of shale and limestone	6
Limestone; oolitic at top; ostracods; (?*Garwoodia* and *O. kershopensis* occur at this horizon farther upstream)	⅓
Shale, weathering rusty	3½
Shale, dark grey slickensided; thin limestone bands	9

BOGSIDE LIMESTONE [5411 7821]

	ft
Limestone, grey massive; abundant crinoids and *A. teres*	17
Shale, dark grey; thin limestone bands	4¾
Limestone, grey; shaly partings; abundant crinoids and *A. teres* in bands	28½

LYNEBANK BEDS

	ft
Alternating bands of shale and limestone; abundant *Myalina sp.* [5411 7821]	18
Limestone, grey; shale bands	3
Shale, grey contorted; in river bed	12
Limestone, grey sandy ostracodal	¾
Shale, grey, and sandy shale; hard limy bands containing *Myalina pernoides*	2
Shale, soft grey; sandy bands	5
Sandstone, grey brown-weathering, medium-grained current-bedded	4½
Shale, dark grey; sandy bands and limestone partings	28½
Limestone, dark grey (inverse dip to east)	6
Alternating thin bands of shale and limestone (oolitic band at this horizon in Hole of Lyne section [5432 7885])	17
Shale, dark grey calcareous shattered	16½
Alternating bands of dark grey calcareous shale and limestone, rare thin sandy bands	13½
Limestone, dark impure	2
Shale, dark; limestone bands	2½
Not exposed	10½
Shale, dark sandy micaceous	5½
Alternating bands of calcareous shale and limestone; ostracods	10
Limestone; gastropods and ostracods	¾
Shale and limestone in bands; sandy partings	19
Shale, contorted; dip almost vertical	9
Limestone, oolitic	¼
Shale, dark, and sandy shale; thin cementstone bands	27
Limestone, grey impure flaggy sandy and micaceous; locally slipped	8
Shale, grey; thin median limestone band; plants	1½
Shale, hard grey brecciated (?slip breccia)	2
Shale, hard dark grey fragmentary calcareous	1¾
Cementstone, flaggy	½
Shale, dark grey	1
Shale, dark sandy; thin limestone partings	14
Limestone, dark grey; abundant ostracods at base	1
Shale, dark; thin limestone bands	8
Limestone, dark, bivalves and ostracods	½
Shale, dark sandy; thin limestone bands	14
Shale, dark grey; *partly obscured* (serpulid limestone at this horizon in Hole of Lyne section)	9½
Shale, dark; limy bands crowded with *Myalina*	4½
Shale, sandy; thin limestone bands; planty and micaceous at base	7½

	ft
Alternating bands of grey limestone and dark shale	7
Shale, grey sandy; sun cracks ..	3
Shale and limestone in bands ..	4¼
Shale, dark; thin limestone and cementstone bands; abundant bivalves	11
Remainder of section measured upstream beyond small tear fault [5432 7841]	
Remainder of previous item ..	14
Shale, dark grey sandy micaceous	4
Alternating bands of shale and limestone; bivalves abundant locally	23
Cementstone, rotten	2
Shale, dark partly sandy; limestone bands; bivalves and ostracods	10
Limestone, blue-grey crinoidal ..	½
Shale, crinoidal calcareous; merging downwards into limestone..	1¼
Shale, crinoidal calcareous ..	2½
Shale, dark	8
Limestone, dark	4¾
Shale, dark	5
Limestone	½
Shale, calcareous	1
Limestone, grey; ostracods ..	1
Cementstone	¼

	ft
Limestone, massive grey; shaly at top; ostracods and *Spirorbis* ..	5½
Cementstone	¼
Shale, dark; thin limestone ..	2¾
Limestone; *Spirorbis*	¼
Section continues unbroken [5438 7850]	
Alternating bands of cementstone and shaly limestone, locally brecciated	3
Limestone, grey; abundant ostracods	¼
Alternating bands of shale and limestone	3½
Not exposed: shale and cementstone upstream..	4
Limestone, grey; bivalves ..	½
Shale, dark grey calcareous; thin bands of limestone crowded with bivalves and scaphopods	2½
Shale, dark	1½
COMMON FLAT LIMESTONE	
Limestone, dark hard; algoolite 1 ft from top and thin shale bands at base	4⅔
Limestone, dark grey; shaly partings; bivalves and ostracods abundant	3¾
Limestone, massive fine-grained; rare ostracods	5¾
Limestone, dark flaggy shaly..	7

River Black Lyne, north of the Dappleymoor Fault

6-in NY 47 N.E. and 47 S.E. Measured by J. B. W. Day.
Shown graphically as Section BL. 2 in Plate V and Fig. 18.

	ft
UPPER BORDER GROUP	
CUMCROOK LIMESTONE	
Limestone, compact grey; and calcareous crinoidal sandstone [loc. 70e: 5009 7452]..	30
Sandstone, massive grey rooty ..	10
Shale, grey; carbonaceous layer and thin coal near base.. ..	8
Sandstone, massive current-bedded	6
Shale, grey sandy..	4
Limestone, hard grey slightly earthy	2
Shale, sandy grey, flaggy bands ..	10
Coal	⅓
Fireclay-mudstone, grey shaly ..	3
Coal	⅓
Fireclay-mudstone, shaly ..	2
Coal	⅓

	ft
Shale, sandy grey; rooty at top ..	10
Sandstone, yellow-weathering; calcareous	1
Limestone, fine hard splintery grey; brachiopods and *Lithostrotion sp.*	5
BULLRIGG SANDSTONE	
Ganister, blue-grey	7
Ganister, flaggy blue; shale bands	4
Sandstone, grey rooty; in beds 2 to 3 ft thick; forms cliff on right bank [5000 7456]. For petrography see p. 217 ..	20
Shale, grey; plant debris.. ..	5
Shale, sandy, and grey argillaceous sandstone	6
Not exposed—small fault ..	2 to 3
Sandstone, blue-grey rooty; beds	

	ft
dip into fault	4
Mudstone, shaly; plant debris	8
Limestone, hard grey earthy; slightly sandy; on left bank	5
Fireclay mudstone, sandy	1
Ganister, blue-grey	6
Mudstone, sandy shaly; sandstone bands	7
Not exposed	30 to 35
Shale, dark grey	8
UPPER NETHERHILL SEAM	
Coal, shaly	½
Shale, dark	2½
Sandstone, massive	6
Shale, very sandy; sandstone ribs	4
Sandstone, massive	2½
Sandstone, very flaggy	6
Sandstone, massive	10
Shales, dark sandy; forming cliff in right bank	25
LOWER NETHERHILL SEAM	
Coal, shaly—old adit in right bank [4983 7472]	½
Fireclay, shaly	2
Sandstone, very flaggy	15
Shale, sandy	2
Limestone, impure sandy; small brachiopods, stick bryozoa and *Bellerophon sp.*	1
Shale, dark grey; limestone ribs containing *Dyscritella nana* (loc. 14a)	15
Limestone, impure; crop repeated by small fault	2
Mudstone, partly obscured	5
Limestone	½
Mudstone	1
Not exposed	35 to 40
Sandstone, hard grey; calcareous	6
Shale	1
Ganister, blue-grey	6
Shale, grey; in right bank	2
Limestone, grey earthy	2 to 3
Shale, grey; in right bank	2
Sandstone, light grey flaggy yellow-weathering; forms cliff in left bank	12 to 14
Shale, grey	8
Shale, very sandy calcareous	3
Shale, grey; sandstone ribs	6 to 7
Sandstone, rooty	3
Shale, grey sandy	5
Limestone, grey; crinoidal	2
NORTH MEADOW SANDSTONE	
Sandstone, whitish and light grey rooty in beds 1 to 2 ft thick	25
Shale, grey; flaggy at top	7
Limestone, grey, tuffaceous in top 2 ft, impure and earthy at base	8
Shale, grey sandy; limy ribs; bryozoa and rhynchonellids	15 to 20
Limestone, grey sandy	3
Shale, grey; fossiliferous at top	3½
Limestone, grey very sandy	2½
Shale, sandy calcareous	2
Sandstone, grey micaceous flaggy	6
Shale	2
Coal, canneloid, and carbonaceous shale; 2 yd south of stream mouth on left bank	⅓
Fireclay-mudstone	½
Mudstone, shaly	¾
Ganister	½
Shale; in stream mouth; left bank	3
Limestone, fine grey; *Productus garwoodi*	1½
Shales, grey; *poorly exposed*	5
OAKSHAW LIMESTONE	
Limestone, fine hard grey displaying differential weathering; shaly towards base; crinoids and brachiopods [4989 7510]	16
OAKSHAW COAL	
Coal, rather shaly	¾
Fireclay-mudstone, sandy	1
Shale, sandy grey	2
Limestone, flaggy grey	4
Shales, sandy grey calcareous; mostly submerged	18
CLATTERING BAND	
Limestone, fine grey [loc. 14h: 4987 7511]	8

MIDDLE BORDER GROUP

	ft
Sandstone, grey flaggy calcareous; rooty	4
Shale, calcareous; thin limestone bands; passing downwards into sandy fireclay-mudstone	14
OAKSHAW SANDSTONE (for petrography see p. 216)	
Sandstone, massive current-bedded; forming crag [4995 7528]	25
Sandstone, grey; calcareous	4
Sandstone, current-bedded; limy bands	9

	ft
Shale, sandy calcareous; shell bed 3 ft from top (loc. 46a)	9
Limestone, grey sandy; ?algal	½
Shale, dark sandy	6
Limestone	½
Shale, grey	8
Limestone, grey flaggy	4
Not exposed	3
Limestone, flaggy; ?algal markings on weathered surfaces	7
Sandstone, rooty calcareous; becoming less calcareous towards base	25
Shale, sandy; less sandy towards base	2
Limestone, fine splintery; rare nests of inorganic ooliths	2
Coal, rather shaly; exposed in left bank [4985 7519]	¾
Fireclay, dark shaly; grading down into fireclay-mudstone	2
Shales, sandy; scattered plant remains	8¼
Limestone, grey shelly; ?algal pellets and ostracods	2½
Shales, grey; limy nodules and bands	6
Limestone, grey; shale partings (loc. 45b) and ostracods	3
Shale, carbonaceous	—
Shale, grey; greenish limy ribs at base	25
Fireclay-mudstone, dark	11
Sandstone, grey; calcareous	3
Shale, grey; calcareous	1
Limestone, fine grey; earthy at base	6
Not exposed (probably shale)	5
Sandstone, calcareous	3
Shale, grey; limestone bands (extending up to Dodgsontown Ford)	5
Not exposed	—
Limestone, grey earthy unfossiliferous; exposed in left bank [4996 7567]	6

River Black Lyne, south of Dappleymoor Fault

6-in NY 47 S.E. and 57 S.W. Measured by J. B. W. Day.
Shown graphically as Section BL.1 of Plate V.

	ft
UPPER BORDER GROUP	
Shale, red and purple sandy; small nut-like limy concretions and at least one thin bed of red limestone, partly obscured by shingle	20
Shale, red and purple sandy; bands of dark red marl	15
Marls, red and grey	4
BLACKLYNE BRIDGE LIMESTONE	
Limestone, red; sparsely crinoidal; rare single corals and colonies of *Lithostrotion* aff. *martini*: (loc. 70g)	8
Shale, red and purple, sandy; marl bands and hematitic nodules	12
Sandstone, fine to medium-grained current-bedded flaggy dip normal	20
Shale, very sandy red	12
Marl, red and grey	1½
Sandstone, purplish flaggy current-bedded	22
Marl, red; thin sandy parting	1
Sandstone, purplish current bedded	30 to 35
Shale, red sandy, and marl; some gaps, dip steepening	20
Sandstone, massive purplish	6
Sandstone, flaggy	3
Limestone, fine-grained brick red (100 yd south of bridge): crop is repeated by folds (pitching, direction 075° at 5–10°) in foundation of bridge on right bank	1
Sandstone and shale in alternating beds	16
Sandstone, massive pink to white: dip direction 210° at 40–50°	8 to 9
Marl, red	7
Sandstone, purplish	4
Not exposed, some evidence of marl	40
Shale, red, sandy and marl; *left bank*	14
Sandstone, massive; *forming waterfall*	3
Shale, red, sandy and marl	6
Limestone, brick-red	1
Shale and marl; *submerged*	5
Sandstone, whitish fine- to med-	

	ft
ium-grained massive current-bedded	21
Not exposed	30
Sandstone, yellowish massive; shattered in river bed; repeated by a small fault and again crops out as a cliff [4975 7356]	40
Sandstone, red flaggy	10
Not exposed	3 to 4

WHITEHOLME LIMESTONE

	ft
Limestone; red at top, yellowish at base	12
Marl, red; *submerged*	2
Limestone, red	1
Marl, red and green; *Lithostrotion pauciradiale* and *Semiplanus sp. nov.* in right bank (loc. 70d)	3
Sandstone, purplish medium-grained; *right bank*	6 to 7
Marl, red and green; *right bank, submerged*	5
Limestone, red; *right bank, submerged*	1½
Sandstone, purple	6
Shale, purple very sandy	9
Sandstone, purple massive medium-grained; *forming cliff on right bank*	35
Not exposed	15
Fireclay, reddish	½
Coal, badly weathered; *right bank* [4967 7372]	¾
Fireclay, grey	⅓
Sandstone, yellow-weathering soft rooty	1
Sandstone, grey-striped argillaceous	1¼
Sandstone, yellow-weathering flaggy current-bedded	7½
Fireclay, carbonaceous shaly	½
Coal, bright	½
Seatearth, grey very sandy	½
Sandstone, yellowish massive	12
Not exposed	1
Shale, dark grey	½
Fireclay	¾
Marl, grey and purple; partings of limestone	4
Sandstone, purple massive	22
Sandstone, flaggy; purplish thin shale bands (right bank)	9
Shale, grey very sandy; flaggy bands	12
Sandstone, purple flaggy	28
Limestone, grey; fossiliferous (loc. 70b) some argillaceous partings	7
Sandstone, hard rooty	3
Fireclay, dark shaly; thin layers of coal	2
Shale, grey slightly sandy	6
Sandstone, purple	6
Shale, grey; fossiliferous	2
Sandstone, flaggy	1½
Shale, dark grey; very fossiliferous (loc. 70c)	8 to 9
Sandstone, calcareous; very fossiliferous	½
Shale, dark grey nodular	7
Limestone, grey and yellowish; *Lithostrotion martini*, *Syringopora sp.* and *Bellerophon sp.* (loc. 70c)	10
Fireclay, grey	¼
Fireclay-mudstone, grey	1
Shale, dark grey	4
Limestone, sandy	¼
Sandstone, purplish massive and flaggy	10
Sandstone flags	2
Shale, purplish very sandy	1½
Shale, grey sandy	2½
Limestone, compact; sandy at base, red-stained in part	2
Sandstone, purplish massive current-bedded	45
Mudstone, grey shaly; fossiliferous (*left bank*)	2
Not exposed	3
Sandstone	1 to 2
Marl, red and shales; poorly exposed	7 to 8
Limestone, grey hard, slightly sandy; *in right bank* [4999 7410]	3
Sandstone, yellow-weathering greyish rooty; calcareous in places	2
Shale, very sandy	¾
Ganister, grey	1
Sandstone, grey rooty; argillaceous	6
Ganister, white	1
Sandstone, grey rooty; argillaceous, bivalves	3
Not exposed	5 to 6
Shale, grey; fossiliferous, fenestellids and brachiopods	3
Limestone, grey very sandy; (forms top of waterfall)	3
Sandstone, purplish; left bank	6

	ft
Sandstone, purplish flaggy	6
Not exposed	2
Sandstone, grey argillaceous calcareous	3
Limestone, grey	1 to 2
Sandstone, grey rooty; partly calcareous, repeated twice by faults; the remainder of the section is measured in the mouth of Farluan Sike [5016 7431]	18
Not exposed	3 to 4
Limestone, grey compact	4
Shale, grey calcareous; superabundant *Bellerophon sp.* (loc. 72c) (also exposed in the Back Burn [4957 7413])	1
Shale, grey	6
Shale, carbonaceous	1
Fireclay, grey	1
DAPPLEYMOOR FAULT	

River Irthing upstream from Crammel Linn

6-in NY 66 N.W., N.E., 67 S.W., S.E. Measured by J. B. W. Day.
Shown graphically as Section I.1 in Plate V. Loc. 77c.
For petrography see p. 217

	ft
UPPER BORDER GROUP	
Shale	6
LEAHILL LIMESTONE	
Limestone, grey hard [6625 7063]; abundant colonies of *Lithostrotion martini*, *L. portlocki*, *Echinoconchus elegans*, *Martinia?*, *Semiplanus sp. nov.*, *Spirifer cf. trigonalis*, *Bellerophon sp.* and *Naticopsis*	9½ to 10
Not exposed	55
Sandstone	3
Not exposed	2
APPLETREE LIMESTONE	
Limestone, hard grey yellow-weathering [6590 7053]; *Buxtonia sp. nov.*, *Composita ambigua*, *Echinoconchus* aff. *elegans*, *Semiplanus sp. nov.*, smooth spiriferoids, *Spirifer* cf. *trigonalis*, *Straparollus sp.*, pectinoid fragment, also colonies of *L. martini* (not collected)	9
Shale; *L. martini*	4
Sandstone, slightly calcareous; rare *L. martini*	3 to 4
Not exposed	15
Sandstone	3 to 4
Shale	2
Limestone, shaly; productids	5
Shale, calcareous; *poorly exposed*	5
Sandstone, calcareous	5½
Not exposed	6 to 10
Shale, thin limy ribs	12
Not exposed	4 to 5
FORSTER'S HILL LIMESTONE	
Limestone, grey massive; rare shale bands, folded into shallow dome and affected by minor fault [6556 7056]; *Caninia?*, *L. martini*, *Syringopora sp.* and *Spirifer* cf. *trigonalis*	6 to 7
(This horizon is 10 to 11 ft thick in Forster's Hill Sike where it contains abundant *Semiplanus sp. nov.*)	
Shale; sandy and calcareous at top, *partly obscured* (measured in Forster's Hill Sike)	12 to 14
WILEY SIKE LIMESTONE	
Limestone, sandy shelly, and calcareous sandstone; *Semiplanus sp. nov.*, *Spirifer* cf. *trigonalis*, smooth spiriferoids, *Sanguinolites* sp. [6554 7045]	15
Not exposed	2 to 3
Shale; plant debris; carbonaceous horizons and one thin band of limestone; *Georgethyris elliptica* (Phillips) and *Spirifer sp.*	16
SPY RIGG SANDSTONE	
Sandstone, flaggy	5
Shales, sandy, and flaggy sandstone; thin limestone band near top	14
Sandstone, orange-weathering; calcareous bands	7
Shales, black pyritous; carbonaceous bands up to 4 in thick	10

	ft
Sandstone, slightly flaggy	4
Coal	½
Shale, dark; plant debris and carbonaceous layers	12
Sandstone, flaggy	2
Shale	6
Sandstone, calcareous	4
Shale	6
Sandstone, flaggy	2 to 3
Shale, sandy; *partly obscured*	14
Sandstone, flaggy slightly calcareous	3 to 4

THROSSBURNFOOT COAL

Coal [6506 6999], right bank 5 to 7 in	½
Fireclay-mudstone	⅓
Shale; thin coal near base and limy nodules at top; plant remains, *Bellerophon sp.*, *Naiadites obesus* (Horizon of Irthing Shell Bed)	15
Shale, thin limestone bands; spines of *Archaeocidaris sp. nov.*, *Fenestella futex*, *F. sp.*, trepostomes, *Buxtonia sp. nov.*, *Linoproductus sp.*, *Pleuropugnoides* cf. *pleurodon*, *Punctospirifer scabricosta*, gastropods and nautiloids	6

SPY HOLE LIMESTONE

Limestone, ochreous very sandy or calcareous sandstone; trepostomatous bryozoa, *Echinoconchus* cf. *punctatus*, *Productus*?, *Punctospirifer* cf. *scabricosta*, *Aviculopecten* aff. *interstitialis*, *Myalina*?	about 15
Shale; calcareous bands; rather dark and carbonaceous towards top	15
Sandstone	10
Shale; yellow-weathering limestone band of varying thickness	9
Sandstone, flaggy	6
Shale, thin coaly bands	6
Shale and limestone, alternating in thin bands	2
Shale	8

LAMPERT SANDSTONE

Sandstone, massive (for petrography see p. 217)	12
Shale	3
Sandstone, grey	1½
Shale	6

UPPER MILLERHILL LIMESTONE

[6464 6976]

	ft
Limestone, grey massive	4½
Limestone, shaly impure	4½
Not exposed – probably shale	15

LOWER MILLERHILL LIMESTONE

[6458 6970]

Sandstone, flaggy calcareous	6
Limestone, massive bedded; flaggy and sandy at top	4
Limestone, shaly	4
Limestone, massive; abundant ?worm tracks	4

POPPINGSTONE SANDSTONE

Sandstone, massive; calcareous horizons	15
Shale, sandy; flaggy calcareous sandstone bands	12
Shale, sandy, and calcareous sandstone, thin hard sandy limestone at top	5
Shale, slightly sandy	3
Limestone, yellow-weathering fossiliferous; resembles cementstone	1
Limestone, very shaly, and calcareous shale	2¾
Shale, dark; carbonaceous layers; thin coal at top	12
Sandstone, flaggy, calcareous lens; abundant *Bellerophon sp.*	2¾
Shale, sandy; uneven base; appears to be banked up against the top of the underlying sandstone; possible disconformity	2 to 4

COLLERING SANDSTONE

Sandstone, massive; top uneven; rare coaly smuts	30
Shale	1½
Limestone; lens	up to 2
Coal	½
Fireclay-mudstone	⅓
Shale, sandy; carbonaceous layers	9

GREEN GROVE SANDSTONE

Sandstone, rather flaggy	15
Shale	1
Limestone, yellow-weathering	1
Shale, carbonaceous; coal layers	1
Shale; plant debris	9
Limestone, earthy sandy	2
Shale, sandy; sandstone ribs	10

	ft
Sandstone, current-bedded	4
Coal	⅓
Shale, sandy; sandstone ribs	15 to 20
CRAMMEL LINN SANDSTONE	
Sandstone, massive current-bedded; forming waterfall; terminated by fault [6403 6966]	20

River Irthing between the mouth of Sunday Burn and Sundayburn Linn

6-in NY 67 S.E. Measured by J. B. W. Day.
Shown graphically as Section I. 2 in Plate V. Loc. 77b

	ft
UPPER BORDER GROUP	
Shale; in mouth of Sunday Burn [6920 7230]	2
Sandstone	2
Not exposed	1
Limestone, yellow-weathering; *Naticopsis sp.* juv., orthocone nautiloid and ostracods	1 to 2
Not exposed; sandy shale debris	5
Sandstone, calcareous; '*Camarotoechia*' *sp.*, *Lingula sp.* (2.5 cm long), *Euphemites sp.*, *Aviculopecten* aff. *interstitialis*, *A. sp.*, *Edmondia sp.*, *Leiopteria divisa*, *Myalina*?, *Polidevcia attenuata*, *Schizodus axiniformis*	1
Not exposed; some sandstone in river bed	6
Shale, dark planty	6
Limestone, shaly planty; sandy micaceous shale containing *Naiadites sp.* near top, with '*Camarotoechia*' *sp.*, *Aviculopecten sp.*, *Leiopteria divisa* and cochliodont fish tooth	10
Limestone, dark brownish-grey; indeterminate gastropods	1½
GAVELOCK BAND	
Shale, black carbonaceous; *Curvirimula*? and superabundant ostracods (crushed) [6908 7243]	⅓
Coal—adits in both banks	at least 1
Shale, dark grey; *Lingula sp.*, 2½ ft above base and *Aviculopecten interstitialis*, *A. sp.*, *Naiadites crassus* Fleming and ostracods	5
Coal	½
Fireclay, shaly	½
Shale, sandy ferruginous planty	7
Sandstone, calcareous; *Punctospirifer scabricosta*, *Productus cf. garwoodi*, *Pleuropugnoides pleurodon*, *Bellerophon sp.*, *Naticopsis sp.*, *Aviculopecten sp.*, *L. divisa*, cf. *N. crassus* and ostracods	1½
Shale with hard limestone rib 2 ft above base; *Fenestella sp.*, *Composita ambigua*, *Pleuropugnoides pleurodon*, *Aviculopecten sp.* and *Schizodus sp.*	7
Sandstone; massive lens; in right bank it transgresses the underlying beds and rests directly on the Leahill Limestone	0 to 12
Sandstone; plant remains	2
Coal smut 1 in	—
Shale	6 in to 1
LEAHILL LIMESTONE	
Limestone, banded; very fossiliferous; *Lithostrotion martini*, *L. portlocki*, *Productus*?, *Semiplanus sp. nov.*, *Spirifer sp.* (*trigonalis* group)	10 to 12
Shale—*partly obscured*	5
Shale, calcareous passing into limestone laterally; zaphrentoid coral, *Archaeocidaris sp.* (spines), *Echinoconchus* cf. *punctatus*, *Productus*?, *Naticopsis sp.* juv.	3
Shale, carbonaceous	½
Fireclay, dark shaly	¾
Limestone, hard grey slightly banded; uneven base; the limestone infills (?erosion) hollows in the top of the underlying coal (Fig. 24)	¾
Coal; uneven top, apparently eroded	¼
Shale, sandy, irony, calcareous band 4 ft above base; *Pleuropugnoides* cf. *pleurodon*	11
Sandstone, gritty calcareous, very ferruginous at top; *Fenestella sp.*, '*Camarotoechia*' *sp.* s.l., *Aviculopecten sp.*, *Edmondia*?, *Leiopteria* cf. *divisa* (common), *Myalina pernoides*, *Polidevcia attenuata*, cf. *Promytilus oblon-*	

	ft
gus, *Sanguinolites* cf. *tricostatus*, *Schizodus*, ostracods	2½ to 3
Coal, 1 to 2 in	—
Shale; fireclay bands and carbonaceous partings; rare limy nodules	10
Limestone, banded sandy ..	1
Shale, sandy; plant remains ..	6
Shale, calcareous; abundant colonies of *Lithostrotion martini*, also *Spirifer trigonalis*	4

APPLETREE LIMESTONE [6896 7272 to 6898 7264]

	ft
Limestone, grey fossiliferous massive; becoming more shaly and less massive in bottom half; *Lithostrotion martini*, cf. *Composita ambigua*, *Echinoconchus* cf. *elegans*, *Semiplanus sp. nov.*, *Spirifer* cf. *trigonalis*, *Aviculopecten sp.*, smooth pectinoid fragments, *Edmondia sp.*, cochliodont fish tooth; small fault terminates crop	14
Shale, calcareous; abundant colonies of *Lithostrotion martini*, also *Fenestella frutex*, *Buxtonia sp. nov.*, '*Camarotoechia*'?, *Productus*?, *Leiopteria* cf. *divisa*	4
Limestone	¾
Shale, dark; ironstone nodules and carbonaceous partings, rare calcareous bands; plant debris ..	28
Mudstone, shaly; *Naticopsis sp.*, *Straparollus* (*Euomphalus*) cf. *calyx*, *Polidevcia attenuata*, and coiled nautiloid?	7
Limestone, sandy	1
Not exposed	8 to 9
Limestone, sandy crystalline; showing traces of superficial reddening near water's edge ..	2
Not exposed, probably mostly shale, but one thin crystalline limestone 20 ft above base ..	45 to 50

FORSTER'S HILL LIMESTONE

	ft
Limestone, slightly shaly; *Lithostrotion martini*, '*Camarotoechia*' *sp.*, *Productus garwoodi*, *Semiplanus sp. nov.*, *Spirifer trigonalis*, smooth spiriferoids *Bellerophon sp.*, *Acanthopecten*?	5½
Shale, calcareous; grading down into sandy flaggy limestone, *Archaeocidaris sp.* (spines), *Fenestella frutex*, '*Camarotoechia*' *sp.*, smooth spiriferoid, *Punctospirifer*?, *Sanguinolites*?, Stroboceratid nautiloid ..	8½
Shale, flaggy bands	2¼
Coal	¼
Shale, dark grey	13
Shale, hard calcareous; *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.* ..	⅔
Shale, dark grey	2
Shale, hard calcareous; *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Productus*?, *Naticopsis sp.*, *Myalina pernoides*, cf. *Naiadites crassus*, *Sanguinolites sp.* ..	¼
Mudstone, black shaly; *Fenestella frutex*, trepostomes, '*Camarotoechia*' *sp.*, *P. scabricosta*, *Spirifer* cf. *trigonalis*, *Retispira sp.*, *Leiopteria divisa*, *Polidevcia attenuata*, *Schizodus sp.*, pectinoids	6
Coal	½
Shale, brownish-grey, rooty at top	7
Shale, sandy; carbonaceous bands; plant fragments	12

SPY RIGG SANDSTONE

	ft
Sandstone, massive	12
Not exposed, probably sandy shale	12
Sandstone, massive; forming Moss Catherine waterfall [6858 7296] and, further upstream Sundayburn Linn ..	50

River Lyne 1

6-in NY 47 S.E. Measured by J. B. W. Day.
Shown graphically as Section L.1 in Plate V.

	ft
LIDDESDALE GROUP	
Sandstone, flaggy current-bedded; shattered adjacent to crush-belt [4859 7150]	10
Shale, red and marls	6

	ft
Marl, red; packed with *Lithostrotion junceum*, rare *Semiplanus*	1 to 2
GOAT ISLAND LIMESTONE	
Limestone, red; *Semiplanus*? and bivalves (loc. 96)	2½
UPPER BORDER GROUP	
SHANK WOOD SANDSTONE	
Sandstone, purplish; massive and flaggy; poorly exposed marl bands	50 to 60
Sandstone, purplish medium-grained current-bedded	50
Sandstone, soft flaggy, and sandy shale; *submerged*	6
Sandstone, purplish mostly flaggy; *submerged*	50 to 60
Shales, red very sandy; striking upstream and passing laterally to current-bedded massive sandstone	20 to 35
Sandstone, soft shaly flaggy	10
Marl, red, and sandy shales; *right bank* [4886 7182]	25
Marl, red; thin limestone ribs, *poorly exposed in left bank* (loc. 68d)	35
Sandstone, flaggy; *left bank*	1½
Not exposed	7
Limestone, red; included marl and sandstone bands; *left bank* [4888 7180]	9
Marl, red sandy, *poorly exposed in right bank*	14 to 15
Sandstone, purple current-bedded	7
Marl, red and grey-green; sandy bands; *right bank*	15

	ft
Sandstone, current-bedded	2
Shale, purple very sandy	6
Sandstone, very shaly, and sandy shales	45
SHANK CASTLE LIMESTONE	
Limestone, red; thin marl bands; *Fenestella sp.* and *Lithostrotion* (loc. 68c and f)	7
Shale, purple very sandy	2½
Marls, red and grey-green; fenestellids and rare bivalves	18
Sandstone, purple massive; *right bank*	18
Shale, very sandy; *left bank*	15
Sandstone, massive; poorly exposed thin marl bands	50
SUSPENSION BRIDGE LIMESTONES (loc. 68c)	
Limestone, red; *Semiplanus*? and gastropod fragments; 2 *yd N.W. of bridge*	3
Marl, red and purple, and shale	6
Sandstone, current-bedded; beneath bridge	10
Limestone, red; *Lithostrotion sp.* and *Syringopora sp.*	3
Sandstone, yellow and purple, current-bedded	18
Shale, sandy, marl, and thin sandstone bands; productid fragments including *Linoproductus sp.* (loc. 68b) 25 ft above base	50
KILN POOL LIMESTONE	
Limestone, red and grey compact; outside of bend [4903 7180]	15 to 18
Sandstone, purplish massive	25

River Lyne 2

6-in NY 47 S.E. Measured by J. B. W. Day.
Shown graphically as Section L.2 in Plate V.

	ft
UPPER BORDER GROUP	
Sandstone, calcareous lenses; right bank [4902 7201]	3
Not exposed	2 to 3
Limestone; red marl bands	9
Strata similar to corresponding part of Section L.1 but including a 2-ft red limestone [4909 7205]	90

	ft
Not exposed	6
SHANK CASTLE LIMESTONE	
Limestone, red; *in left bank*	2
Shales, purple	3
Not exposed	up to 6
Marl, purple and grey-green; *partly submerged*	8 to 9
Sandstone, purplish	12
Not exposed—traces of marl	20

SUSPENSION BRIDGE LIMESTONES	ft
Limestone, red	1
Shale, red, and marl; *poorly exposed*	10
Limestone, red	2
Not exposed (?sandstone)	8
Sandstone, bright red	7
Sandstone, purple current-bedded	20
Not exposed	2
Sandstone	3
Not exposed	5
KILNPOOL LIMESTONE	
Limestone, red [4921 7210]	6
Sandstone, purplish current-bedded; beds overturned	18
Not exposed—marl debris	20
Sandstone, current-bedded	15
Shale and marl	14
Limestone, red crinoidal; *Fenestella sp.* and ostracods	3
Shale, poorly exposed red, and marl; a thin limestone band near base	8
Sandstone, purplish current-bedded massive; sandstone forming cliff on right bank; beds overturned	50
Not exposed	40
Limestone, red crinoidal; cf. *Aviculopecten subconoideus* R. Etheridge jun.	3
Marl, red, and sandy shale	8
Sandstone, current-bedded; shaly at base; forming rapids	20
Not exposed; shale debris	6
Sandstone, current-bedded flaggy; shale bands; forming cliff on right bank	25 to 30
Marl, red; *poorly exposed*	12
Sandstone, massive	10
Not exposed	4
Limestone, red; *Lithostrotion martini; left bank* [4934 7215]	3
Not exposed	3
Marl, red; *right bank*	2
Sandstone, current-bedded	18
Not exposed	4
Limestone, red	4½
Sandstone, purplish current-bedded; rare marl bands; beds overturned	12
	ft
Not exposed; probably soft marl; at deep pool	9
Sandstone, flaggy	6
Not exposed	8
PINK POOL LIMESTONE [4939 7219]	
Limestone, red	5
Marls	3
Limestone, reddish flaggy; *Lithostrotion martini*, *L. portlocki* and *Semiplanus*?	12
Shale and marl	9 to 10
Sandstone, current-bedded flaggy	20
Not exposed; shale debris	18
Marl, greenish striped	2
Sandstone, purplish massive; right bank	12
Sandstone, shaly and flaggy, and sandy shale; rare limy bands; right bank	60
Sandstone, thin marl bands	4
Sandstone, massive purplish current-bedded	25
Marl and sandy shale	12
LANERCOST LIMESTONES	
Limestone, red crinoidal	8
Sandstone, flaggy	8
Sandstone, flaggy; marl bands	15
Limestone, red; bivalve fragments	4
Sandstone, flaggy, and marl	3
Marl; 1-ft lens of red limestone	4
Sandstone, current-bedded	10
Limestone, red; thickness varies along strike	8
Sandstone, purplish	12
Shale, sandy	8
Not exposed	12
Marl, red	2
Limestone, red	3
Shale and red marl; poorly exposed	30
Limestone, red; *Lithostrotion sp.* and productoids; left bank [4951 7214]	—

Although the section continues to the outside of the bend at Crabtree Pool, it is better exposed farther upstream, in the section given below.

River Lyne 3

6-in. NY 47 S.E. Measured by J. B. W Day
Shown graphically as Section L.3 on Plate V

UPPER BORDER GROUP

	ft
Limestone, red [4951 7254] ..	3
Sandstone, massive current-bedded; slightly disturbed ..	12
Not exposed	6
Limestone, red	2
Not exposed	3
Sandstone, flaggy at top ..	18
Not exposed	9
Sandstone, flaggy	6
Not exposed	13

PINK POOL LIMESTONE

	ft
Limestone, red hard crystalline	4
Limestone, soft marly ..	1
Marl, red sandy	3
Limestone, hard crystalline, rare sandy bands; *Lithostrotion martini* and cerioid lithostrotiontids, *Semiplanus sp. nov.*	18
Sandstone, soft flaggy	1
Marl, sandy	3
Sandstone, thin marl bands ..	12
Shale, sandy, sandy ribs	15
Limestone, red	3
Marl, sandy	6
Limestone, red impure	up to 3
Marl, sandy	6 to 7
Sandstone, massive	13
Sandstone, flaggy	6
Sandstone, massive	4
Marl, red	8
Sandstone, flaggy	9
Shale, sandy	12
Sandstone, flaggy	2½
Shale, purple	4
Sandstone, purplish massive flaggy	25
Shale, purple sandy; thin limestone rib near top	20
Not exposed	3
Sandstone, flaggy	10
Not exposed	5 to 6

LANERCOST LIMESTONES

	ft
Limestone, red crinoidal; productoids	8
Not exposed	15
Limestone, red crinoidal ..	6
Shale, and sandstone	6
Limestone, red; productoids ..	1½
Marl	2
Sandstone, massive	8
Not exposed	3
Limestone, red massive; colonies of *Lithostrotion* in positions of growth and patches of ?*Girvanella*	15
Not exposed	8
Sandstone, massive	8
Not exposed	10
Sandstone, massive; flaggy towards top	12
Sandstone, rather flaggy ..	6
Not exposed	15
Limestone, red [4965 7230]; just north of stream mouth ..	3½
Sandstone; at stream mouth ..	30
Not exposed mostly sandy marl, sandstone ribs on right bank ..	25
Sandstone, massive	4
Shales, sandy, and marls; *poorly exposed*	25 to 30
Sandstone, flaggy at top	35
Not exposed	10
Sandstone	3
Marls, red sandy	3
Sandstone, flaggy current-bedded; beds overturned	12
Shales, sandy ribs	12
Limestone, red; shaly at base ..	18
Not exposed	8
Sandstone	45
Marls (probably)	25

?CUMCROOK LIMESTONE

	ft
Limestone, red crinoidal; left bank [4967 7228]	8
Not exposed	25
Limestone, red	2
Not exposed	5
Limestone, red; colonies of *L. martini*	12
Not exposed	12
Sandstone, massive; dip apparently discordant	6
Not exposed	4
Sandstone (may be slipped mass)	12
Sandstone, red calcareous ..	3
Limestone, red sandy crinoidal; striking across Crabtree Pool ..	3
Sandstone, rather flaggy ..	15

	ft
Shale, very sandy; sandstone ribs	20
Sandstone, calcareous	2
Sandstone, flaggy; marly bands	24
Sandstone, slightly flaggy	12
Marls, red	7
Sandstone underlain by red marls; small turreted gastropods [4971 7222]	5

River White Lyne between Goat Island–Lyne Thrust and bend 120 yd N.E. of Selbystown Farm

6-in NY 47 S.E. Measured by J. B. W. Day.

	ft
UPPER BORDER GROUP	
Limestone, red [4976 7305]	3 to 4
Not exposed	12
Sandstone, purplish current-bedded; dip steep, beds overturned	25
Not exposed	3
Limestone, red, earthy; '*Camarotoechia*' ?, productid fragments, *Martinia sp.*, *Straparollus* ?, *Edmondia* ? (traversed midstream by minor east–west dextral strike-slip fault)	5
Not exposed	8
Shale, sandy purplish	15 to 16
Sandstone, purplish flaggy soft fine- to medium-grained	45
Limestone, red earthy	2
Marl, red and grey-green	2½
Sandstone, white; patchily reddened	12
Shale, red sandy	5
Sandstone, white fine- to medium-grained; brick-red blotches	15
Sandstone, purplish flaggy; shaly at top	12
Sandstone, massive	8 to 9
Sandstone, purple slightly flaggy	10
Shale, red; marly at top	10
Limestone, red earthy; *Lithostrotion* cf. *martini* and *Schizodus sp.*	2
Not exposed: sandstone debris	4 to 5
Sandstone, purplish fine- to medium-grained	18
Shale, red calcareous; *Fenestella sp.*, *Martinia* ?, *Productus sp.*, *Sulcatopinna sp.*	½
Sandstone, wispy-bedded fine-grained purple-striped; dip steep, beds overturned	25
Sandstone	3
Shale and marl, purple sandy	9 to 10
Sandstone, massive; dip steepens towards fault	20
Fault, throwing down to ?east, amount not known [4995 7305]	
Shale and marl, red sandy	12
Limestone, red earthy	2
Marl, red	6
Sandstone, flaggy	6
Sandstone, massive current-bedded	15
Sandstone, purplish flaggy	8
Not exposed: indications of sandstone	15 to 18
Not exposed: sandstone in cliff: contorted shales in river bed	20
Fault [4999 7301]	

River White Lyne, east of the Kaysbank Fault

6-in NY 57 S.W. Measured by J. B. W. Day.
Shown graphically in Fig. 8.

	ft
LOWER BORDER GROUP	
BEWCASTLE BEDS	
Limestone, pink	1¼
Marl, red	1
HIGH GRAINS SANDSTONE	
Sandstone, pink medium-grained; rare flaggy bands	26
Marl, red	¾
JUNCTION LIMESTONE	
Limestone, reddish [5115 7280]	7
Marl, red	2
Limestone, impure	1¼
Sandstone, pink massive	8½
Sandstone, flaggy	6
Sandstone, massive	6

PEEL LIMESTONE

	ft
Limestone, pink; rare *Serpula sp.*	3⅔
Sandstone	10
Marl	2
Limestone, sandy reddish	1½

PLANTATION SIKE SANDSTONE

	ft
Sandstone, medium-grained massive; marl at base	18
Not exposed	6
Sandstone, massive	12
Marl, red	3
Sandstone; flaggy below	6
Shale, red sandy	7 to 8

RIGGHEAD LIMESTONE

	ft
Limestone, red; non-algal	7
Algoolite, red; small '*Ottonosia*'-type algal growths; forms striking pavement-like slabs [5119 7278]	2½
Shale, red	9 to 20
Limestone, impure flaggy	3½
Sandstone; flaggy horizons	12
Shale, sandy; marl bands; fine red silt at base	12 to 14

ASHY CLEUGH LIMESTONE

	ft
Limestone, red; non-algal	8
Shale	6
Limestone, flaggy	2½
Shale, red	30 to 32

EARTHWORK SANDSTONE

	ft
Sandstone, massive current-bedded	90

NEW HOUSE LIMESTONE

	ft
Limestone, red [5126 7278]	2
Algoolite, red; forms striking 'pavement' in midstream	2
Limestone, red; (beds affected by minor sinistral strike-slip fault)	4
Not exposed	50 to 55
Algoolite, red	1⅓
Limestone, red	8½
Not exposed	8
Sandstone, purplish, massive	50

HOLMEHEAD LIMESTONE

	ft
Limestone, pinkish-red impure; rare marly bands	30
Not exposed	18 to 20
Limestone; rare ooliths	4½
Not exposed	8 to 9
Limestone, sandy	1
Sandstone, pinkish massive	30
Not exposed	2
Marl, red	4

KITTY BECK LIMESTONE

	ft
Limestone, red; thin algoolite bands near base and top	7½
Not exposed (probably includes Bogside Limestone)	120 to 130
Sandstone, pinkish	1
Not exposed	7 to 8
Limestone, reddish fine compact hard [5136 7276]	20

River White Lyne, north of Lynecrook Farm

6-in NY 57 S.W. Measured by J. B. W. Day.
Shown graphically as Section WL.1. in Plate V.

UPPER BORDER GROUP

	ft
Sandstone, white purple-stained fine- to medium-grained current-bedded; dip steep, beds overturned [5019 7336]	45 to 50
Not exposed: some shale and marl debris	5 to 6

?BLACKLYNE BRIDGE LIMESTONE

	ft
Limestone, purplish sandy [5020 7336]; *Productus sp.*, *P. garwoodi*, *Araeonima* cf. *conica*, *Retispira sp.*, pectinoids and bivalves	1 to 2
Marls and shales, red sandy bands	20
Sandstone, flaggy, purplish, ripple-marked	8
Shale, purple sandy	3
Marl, purple-striped	6
Marl, crushed	1 to 1½
Shale and marl; calcareous sandstone ribs; plant debris at top and '*Camarotoechia*' *sp.*, *Aviculopecten subconoideus*, *Nota-*	

	ft
musium radiatum, bivalves and ostracods 15 ft above base	30
Sandstone, red	4
Marl, red; limestone ribs	8
Limestone, red	2
Marl, red	3
Sandstone, purplish	3
Shale, sandy, calcareous, limestone ribs	13
Limestone, bright red; bellerophontoids [5027 7337]	7
Shale, purplish sandy; sandstone ribs	16
Sandstone, purple flaggy	7
Marl, red; limestone ribs	24
Sandstone, purplish	5 to 6
Marl and shale, red; thin limestone lens	12 to 15
Not exposed	3
Sandstone	1½
Not exposed; shale debris	10 to 11
Limestone, red siliceous crinoidal; *Fenestella sp.*	1 to 2

SPY RIGG SANDSTONE

	ft
Sandstone, purplish; marl bands	12
Sandstone, red soft calcareous	6
Sandstone, white massive medium-grained; purple-stained	40 to 45
Sandstone, purplish massive flaggy current-bedded; beds overturned	50
Marl, red; *Fenestella sp.*, '*Camarotoechia*' *sp.*, *Linoproductus sp.*, costate productoid indet., *Retispira sp.*, *Straparollus sp.*, *Aviculopecten* cf. *plicatus*, *Polidevcia attenuata*, *Promytilus oblongus*, *Sanguinolites* cf. *clavatus;* stroboceratid nautiloid	1
Not exposed	11
Limestone, red earthy; ?*Lithostrotion pauciradiale;* dip almost vertical	3
Not exposed	2
Sandstone, massive flaggy current-bedded; beds overturned	10
Shale, purple sandy	5
[*Several small strike-slip faults, trending east–west, affect the succession hereabouts*]	
Limestone, red	5
Sandstone, purplish massive	8
Shale and marl, sandy; flaggy sandstone ribs; *Fenestella sp.*, *Stenodiscus sp.*, *Buxtonia sp.* [coarse costae], *Punctospirifer scabricosta*, rhynchonelloid or *Stenoscisma sp.*, *Spiriferellina* cf. *octoplicata*, *Retispira* cf. *decussata*, *Donaldina sp.*, *Euphemites* cf. *urei*, *Naticopsis sp.*, *Straparollus sp.* s.l., *Aviculopecten sp.*, *Palaeoneilo laevirostris*, *Polidevcia attenuata*, *Promytilus oblongus*, *Prothyris sp.*, *Schizodus sp.*, stroboceratid nautiloid, ostracods	14

LYNECROOK LIMESTONE

	ft
Limestone, grey red-stained [5037 7333]; *Lithostrotion portlocki*, *Semiplanus*?, *Spirifer sp.*, bellerophontoid?	15 to 18
Sandstone, purplish	12
Marl, red	12
Limestone, red	1
Sandstone	18
Marl and shale, red sandy	6 to 8
Sandstone, purple	8
Limestone, red	1 to 2
Marl, red	2
Sandstone, purple laminated	7
Sandstone, purple massive	5
Marl, purple laminated	6
Sandstone, purple massive	10
Marl, purple laminated	6
Sandstone, flaggy, marl bands at top	10
Sandstone, purple massive, dip vertical	20 to 22
Not exposed; marl debris	10 to 14

LANERCOST LIMESTONES

	ft
Limestone, red hard splintery; *Lithostrotion portlocki*, ostracods and fish fragments [5041 7331]	7
Marl, red	16
Sandstone	1 to 2
Marl, red	7 to 8
Limestone, red hard splintery; *Prothyris oblonga* and *Sanguinolites*? [5041 7331]	8
Sandstone, white purple-stained current-bedded; calcareous bands; beds overturned	20
Not exposed	4

	ft
Limestone, greyish red hard splintery veined; bellerophontoids [5044 7330] ..	9 to 10
Marl, laminated	10
Sandstone	6 to 7
Marl and shale, red	7
Limestone, red	2¾
Sandstone, purplish flaggy ..	25
Marl, red; limestone nodules; *Fenestella sp.*, *Linoproductus*?, *Rugosochonetes* aff. *hardrensis*, gastropods indet., *Prothyris*?, and ostracods 10 ft below top ..	15
Limestone, red	4
Sandstone	18
Shale, red sandy; sandstone ribs	16
Sandstone, purplish massive ..	15
Shale, sandy, sandstone ribs; *Fenestella sp.*, gastropods indet., *Palaeoneilo sp.*, *Sanguinolites* cf. *clavatus*, *Schizodus sp.* ..	6
Sandstone, massive	8
Shale and marl; sandstone bands	20 to 22
Sandstone, flaggy	18
Sandstone, massive	10
Marl, red sandy; turreted gastropod and pectinid fragments ..	8
Sandstone, purplish	15 to 18
Not exposed: shattered sandstone in midstream (Parkfoot Fault)	20 to 24
Sandstone, massive purplish current-bedded	20 to 25
Marl, limestone ribs	12

CUMCROOK LIMESTONE

	ft
Limestone, reddish sandy splintery; *Lithostrotion sp.*, *Fenestella sp.*, *Echinoconchus* cf. *elegans* and spiriferoid indet. [5056 7321]	12
Marl, partly exposed; trepostomatous bryozoan indet., *Fenestella sp.*, *Echinoconchus* cf. *punctatus*, *Productus*?, *Spirifer sp.*, *Aviculopecten* aff. *plicatus* and *Epistroboceras* cf. *sulcatum*	15
Limestone, greyish red, hard; *Caninia*?, *Diphyphyllum sp.*, *Semiplanus sp. nov.*, *Linoproductus sp.* and *Lithostrotion* aff. *martini* [5057 7319]	20
Marl; limestone bands; *Diphyphyllum sp.* and *Semiplanus sp. nov.*	40
Sandstone, purplish; traversed by small strike-slip fault	8
Sandstone, purplish	14
Marl, red; limestone ribs	8
Limestone, red, sandy at top, forms deep pool	10
Marl, red	8
Shale, sandy, sandstone ribs ..	20
Sandstone, purplish massive ..	6
Marl, red; *Fenestella sp.*, '*Camarotoechia*' *sp.*, turreted gastropod, indet. ostracods and trepostome	10
Not exposed	6
Sandstone	10
Sandstone; marl bands	15
Not exposed	12
Marl, red	8

BRYOZOAN LIMESTONES

	ft
Limestone, red shaly; abundant *Dyscritella sp.* (highest occurrence) and *Punctospirifer* cf. *scabricosta*	1 to 2
Sandstone, flaggy; marl bands	10 to 12
Limestone, red; abundant trepostomatous bryozoa and cf. *Stenoscisma isorhyncha* ..	2
Not exposed	6
Limestone, red	2
Not exposed	9 to 10
Limestone, red marly	4
Not exposed	12
Limestone, red	2
Not exposed	4
Limestone, red	2
Sandstone, massive	10 to 12
Marl and shale, sandy; a limestone band	12
Sandstone, purplish white ..	6 to 8
Marl and shale, red	7
Limestone, red	2
Marl, red; limestone nodules ..	5
Sandstone, red [5063 7319] ..	12

River White Lyne, north and north-west of Kaysbank Farm

6-in NY 57 S.W. Measured by J. B. W. Day.
Shown graphically in Figs. 13 and 17 and as Section WL. 2 in Plate V.

UPPER BORDER GROUP

	ft
Shale and marl, red sandy; calcareous nodules containing abundant bryozoa, *Dyscritella sp.*, *Lithostrotion sp.* and cf. *Stenoscisma isorhyncha* [5066 7332]	18
Sandstone, red flaggy; plant remains	10
Marl, red; thin fossiliferous band at top containing *Buxtonia sp.*, *Naiadites crassus* (Fleming), *Sanguinolites sp.* and pectinoid fragments	13
Shale, sandy; sandstone bands	17
Sandstone, purplish massive	6 to 8
Sandstone, thin-bedded flaggy	11 to 13
Sandstone, thin-bedded	10
Sandstone; red limestone band containing *Spirifer sp.*	3
Sandstone, massive	4
Sandstone, grading downwards into shale	2 to 3
Sandstone, massive	4
Shale, red; *Archaeocidaris sp.* [spines]; *Fenestella sp.*, trepostomes and other bryozoa indet.; *Buxtonia* sp., *Echinoconchus* cf. *punctatus*, *Linoproductus sp.*, orthotetid?, *Productus sp.*, rhynchonelloid, *Spirifer sp.*, *Hypergonia sp.*, *Aviculopecten sp.*, *Leiopteria thompsoni*, *Parallelodon* cf. *reticulatus*	8
Sandstone, calcareous	½
Limestone, red	3
Sandstone and shale, alternating bands	55 to 60
Sandstone, hard massive	4
Shale and marl, red; rare sandy bands	25

BRYOZOAN LIMESTONES

	ft
Shale, very calcareous; limestone ribs packed with trepostomatous bryozoa, *Dyscritella sp.*, *Fenestella sp.*, '*Camarotoechia*' *sp.*, costate productid fragments, *Aviculopecten sp.*, *Leiopteria divisa*, *Palaeoneilo laevirostrum*, *Pteronites latus*	8
Limestone, sandy	1¼
Sandstone	1
Shale, red; *Paraconularia sp. nov.*, *Naiadites crassus* (lowest occurrence), *Sanguinolites sp.*, grades down into calcareous shale with limestone ribs packed with trepostomatous bryozoa and *Dyscritella sp.*, *Fenestella* cf. *occulata* McCoy, productid fragment, ?*Stenoscisma isorhyncha* and *Aviculopecten sp.* [5072 7336]	6
Sandstone, purplish flaggy	6
Limestone, red sandy; traversed by small fault	7
Sandstone, flaggy, and shale	25
Shale and marl, red; *Fenestella sp.* at top, bivalves and ostracods at base	10
Sandstone, red calcareous	2
Sandstone, massive-bedded; jointed	20
Marl and shale, red sandy; crushed *Sanguinolites sp.*	14
Sandstone, whitish purple	7
Not exposed	7
Limestone, purple sandy; *Productus* aff. *redesdalensis* and *Spirifer sp.*	2
Sandstone, purplish massive	18
Marl and shale, red; *Fenestella sp.*, trepostomatous bryozoa, *Echinoconchus sp.*, costate productid fragments, *Punctospirifer scabricosta*, cf. *Stenoscisma isorhyncha*, *Aviculopecten sp.*, *Sanguinolites sp.*	6
Limestone, red; *Echinoconchus punctatus* and *Spirifer sp.*, dip vertical [5078 7336]	7½
Shale, sandy; limy bands	12
Limestone, sandy	1
Shale; limy bands; *Spirifer sp.*	6
Limestone, sandy	7
Marl, red; limy bands	8
Sandstone, purplish; dip vertical	14

	ft
Limestone, red; productid fragments, rhynchonelloid or *Stenoscisma sp.* and *Aviculopecten sp.*	2
Sandstone, flaggy hard; marl bands and thin shelly limestone ribs containing *Productus garwoodi*	10

OAKSHAW LIMESTONE

	ft
Limestone, red hard splintery, bryozoa, *P. garwoodi*, *Linoproductus sp.*	10
Shale and marl, red	10 to 12
Limestone red	3
Marl and shale, red	8
Not exposed	6

CLATTERING BAND

	ft
Limestone, red hard [5083 7336]	5
Marl, red at top, greyish green at base; *Lithostrotion martini*, *L. portlocki*, *Productus garwoodi* and *Semiplanus sp. nov.*	30

MIDDLE BORDER GROUP

	ft
Sandstone	12
Shale, red; ostracods	5
Sandstone, purplish	12
Shale, red, marl, and thin limestones; *Leiopteria laminosa*, *Schizodus sp.* and ostracods ..	45
Sandstone, purplish	2
Limestone, red; contorted; left bank	1
Sandstone, purplish; limy bands	10
Oolite, inorganic	1
Marl, red sandy; limy bands ..	10
Sandstone, purplish; slightly calcareous	7
Limestone, ostracods	1
Marl, red; grey-green clayey bands [5089 7338]	35
Sandstone, purplish	9
Sandstone, calcareous; shell debris	1
Shale, red	4
Sandstone, purplish fine-grained	2½
Limestone, sandy	1½
Sandstone, thinly bedded ..	13
Not exposed	6
Limestone, sandy thin-bedded ..	½
Shale, bluish at top, red below ..	2
Sandstone	7
Shale, reddish silty	4
Sandstone	4
Not exposed	2½
Marl, sandy; irony band	3
Shale, red and grey; sandy partings	1½
Limestone, red sandy; cut off near north bank by strike-slip fault trending 065°	3
Sandstone, contorted marl band	8
Marl, sandy at top	8
Shale, reddish sandy; band of bluish mudstone near base ..	8
Shale, reddish brown; *Parallelodon sp.* and ostracods	5
Limestone, sandy; ?*Myalina sp.* and *Schizodus*?	2
Shale, sandy	2
Sandstone, calcareous	5
Not exposed	11
Sandstone, reddish	2
Sandstone, partly exposed ..	25
Shale, sandy	5
Marl, sandy	6
Shale, soft sandy	4
Sandstone, purplish thin-bedded; lowest bed seen in right bank against strike-slip fault (this bed is assumed to correlate with the highest sandstone seen in the left bank to the south of the strike-slip fault)	?
Sandstone (in left bank) shattered against strike-slip fault ..	20
Marl, red and grey-green, some hematitic limestone nodules ..	25
Limestone, red, affected by small strike-slip fault	1¾
Marl, striped red, clayey	11
Limestone, red very sandy marly	1
Marl, red	12
Limestone, red; sandy at base ..	3
Not exposed	4
Limestone, deep red	1
Not exposed	6
Sandstone, red limy and marl ..	10
Sandstone, purplish	15
Shale and red clayey marl ..	12
Sandstone, purple	3
Not exposed: probably flaggy sandstone	8
Sandstone, purple	6
Limestone, brick-red soft, hematitic	1
Sandstone, purple	12
Shale, red sandy; limy lenses ..	12
Sandstone, flaggy	4
Limestone, red; *Myalina sp.* and *Sanguinolites* cf. *plicatus* ..	7½

	ft
Sandstone, purplish massive ..	4
Shale, red and marl	18
Sandstone, massive; worm-tracks	14
Shale, sandy, and marl; poorly exposed	30
Sandstone, purplish	3
Marl, red, and shale; bright red limy lenses	18
Limestone, red sandy	3
Sandstone, purplish flaggy ..	18
Limestone, red sandy	1
Marl, red; limestone bands; *Myalina verneuili*	8
Limestone, red	1
Marl and shale, thin sandstone bands, poorly exposed ..	15
Sandstone, fine, poorly micaceous, but with flaggy bands	20
Shale, flaggy bands	14
Sandstone, purplish massive ..	12
Shale, sandy, and marl; hematitic limy nodules	20
Sandstone, purplish flaggy ..	20
Marl, red striped; flaggy bands ..	6
Sandstone, purplish	6
Marl, red striped	6
Sandstone, purplish flaggy ..	7
Shale, red, and marl; abundant *Lithostrotion sp.* on right bank	12
Limestone, red	3
Not exposed, probably marl ..	8
Limestone, red hard splintery ..	3
Marl, red	8
Limestone, reddish grey shelly ..	3
Marl	7
Limestone, red nodular inorganic; small dextral strike-slip fault ..	1
Not exposed	8
Limestone, red	2
Marl red; disturbed	8
Sandstone, traversed by small strike-slip fault on left bank ..	10
Marl	2
Limestone, red splintery ..	2
Shale, red, and marl	12
Shale, sandy	8
Sandstone, purplish	4
Shale, red, and marl; thin red limestone bands	52
Sandstone, purplish	2
Not exposed	4
Limestone, fine-grained hard splintery; reddened in top 2 to 3 in giving rise to 'blocky' appearance	2½

	ft
Sandstone, purple-speckled ..	8
Marl and shale	12
Sandstone, current-bedded massive	12
Not exposed: some marl debris ..	5
Limestone, red, deep red and soft at top, hard and splintery at base: highest horizon of *Antiquatonia teres*	3½
Marl, red and grey-green clayey ..	5
Sandstone, purple, flaggy ..	12
Algal nodular bed 1 in	—
Shale, purplish sandy	3
Shale, marly	4
Shale, sandy; soft and brick-red at top, shelly at base	10

WHITBERRY BAND

Shale, red and purple	9

LOWER BORDER GROUP

CAMBECK BEDS

Sandstone, purplish	7 to 8
Shale and marl, red with greenish bands; *Fenestella sp.*, bryozoa indet., *Syringothyris sp.*, *Schizodus*?, *Productus*?, *Punctospirifer scabricosta* (lowest occurrence), *Retispira sp.*, *Aviculopecten*?, *Myalina* cf. *pernoides*, *Sanguinolites sp.* (*tricostatus* group); ostracods indet.	51
Sandstone, flaggy	5
Shale and marl, red	7
Limestone, red	6
Marl and shale, red	8
Sandstone, yellowish-purple ..	18
Marl, red striped	10
Shale, red; *Polidevcia* cf. *attenuata*	2
Limestone, red soft marly ..	2
Marl and shale, red	2½
Limestone, soft, red, marly; *Sanguinolites*? [5109 7320] ..	3
Shale, red, and flaggy sandstone ..	18
Limestone, reddish compact ..	3
Sandstone	2 to 3
Marl and shale, red	6 to 8
Limestone, reddish earthy sandy; bands of purer limestone ..	5
Shale and marl; thin red limestone bands; affected by minor strike-slip fault in left bank	25

HILLEND ALGAL BAND

Limestone; large compound algal nodules interspersed

	ft
with many smaller nodules giving the bed a mottled appearance; *Garwoodia sp.* and *Ortonella furcata* [5111 7319]	2¾
Sandstone, flaggy; red-flecked with white at top; bedding slightly contorted	5
Marl; thin compact limestone at base	10
Sandstone, flaggy	1
Not exposed	5

?SYRINGOTHYRIS LIMESTONE

	ft
Limestone, red marly; impure at top with more compact bands; 'honeycomb' weathering at base [5112 7318]	12
Marl, red	1½
Sandstone, red	8 to 9
Limestone, grey red-stained; flaggy at base; repeated by small strike-slip fault in left bank	1¼
Marl, red	2⅓
Sandstone	4
Marl, limy	2
Not exposed	13
Sandstone	3
Not exposed	12 to 14
Limestone, red slightly earthy; small algal nodules in basal 1½ ft on right bank; large compound nodules on left bank	2½
Limestone, red slightly earthy; apparently non-algal; sinistral strike-slip fault in left bank	9½
Not exposed	4
Sandstone, red white-flecked	3
Not exposed	2
Limestone, sandy marly	3
Not exposed	1
Limestone, red; shifted 20 ft by sinistral strike-slip fault on right bank and 10 ft by dextral strike-slip fault on left bank	6
Not exposed	7
Limestone, grey marly red-flecked [5112 7314 and 5113 7311]	4¾
Sandstone, massive	8
Limestone, impure; shale bands	5
Limestone, massive; 3-in algal nodule band with *Girvanella ducii* and *Ortonella furcata*	1½
Limestone, marly, marl bands	7
Limestone, brick-red compact marl bands	1¼
Shale and marl; sandy bands	9
Sandstone	1½
Shale, sandy	1
Limestone, marly	¾
Not exposed	1⅓
Sandstone	2¾
Marl	4½
Limestone, hard	4¾
Not exposed	4¾
Limestone; sandy and marly at top and base	3¾
Sandstone; repeated by sinistral strike-slip fault	15
Not exposed	15
Marl; grading down to limestone at base	4
Not exposed	2
Sandstone	1⅓
Limestone, impure marly	1½
Sandstone, massive; limy lens near top	18
Marl and thin limestone, shattered	9
Not exposed	7 to 8
Sandstone; in right bank against dextral strike-slip fault; amount of lateral displacement unknown, but the sandstone exposed in the left bank against the downstream end of the fault is probably the same	10
Shale; sandy bands; *Antiquatonia teres* and *Acanthopecten sp. nov.*	15

UPPER ANTIQUATONIA BAND

	ft
Limestone, flaggy; abundant *A. teres* [5114 7309]	12
Limestone, red, massive	16
Shale, red	6
Limestone, red nodular algal; *Garwoodia sp.* and *Ortonella furcata*	2
Shale, red	3

BARRON'S PIKE SANDSTONE

	ft
Sandstone, purple-speckled medium-grained current-bedded	30 to 32
Limestone, red nodular algal	3 to 5
Sandstone, purplish	8
Not exposed	10 to 12
Limestone, red	1½
Sandstone, purplish	3
Limestone, red sandy	2

	ft
Sandstone, purplish flaggy	12
Not exposed	5
Limestone, pinkish crinoidal; spiriferoids indet. [5116 7303]	8
Sandstone, purplish massive	26

LOWER ANTIQUATONIA BAND

	ft
Shale and marl, red; *Archaeocidaris sp.*, *Lingula sp.* and *Aviculopecten plicatus*	12 to 14
Limestone and shale, reddish striped; flaggy shelly bands contain abundant *Antiquatonia teres*, *Ovatia bioni*, *Schizodus sp.* and ostracods indet.; dip near vertical	50
Marl, red, *A. teres*	10
Limestone, red; *A. teres*, *Aviculopecten* aff. *plicatus*, *Pteronites latus*, *Sanguinolites* aff. *variabilis* and *Paraparchites*?	5
Marl, red; abundant *Antiquatonia teres* and *Spirifer sp.* (*striatus* group)	5½
Limestone, red	12 to 13

MAIN ALGAL BEDS

	ft
M.A.14	
Limestone and marl, in alternating bands; crinoids and bivalves	14
M.A.13	
Limestone, pink, marly, microfossiliferous, sparsely nodular	5⅓
Shale and marl, red, partly unexposed	8
M.A.12	
Limestone, impure; bivalve fragments indet.	1
Limestone reef, algal; compound nodules commonly encrusting orthoceratids; nodules encrusted with *Spirorbis sp.*; festoon structures (See Pl. IIB) convex upwards to north-west (beds young downstream: beds steeply overturned to south-east)	2
Limestone, pinkish grey shaly; traversed by minor sinistral strike-slip fault along right bank	4
Shale, red	½
Sandstone, purple speckled	1¾
Shale, red marly	1¾
M.A.11	
Limestone, pinkish algal; festoon structures and abundant nodules 3 to 4 cm diameter (Pl. II); algal species include *Bevocastria conglobata*, *Garwoodia gregaria*, *Girvanella amplificata*, *G. ducii*, *G. nicholsoni*, *Ortonella furcata*, *O. kershopensis* and *O. tenuissima*	4
Sandstone; thin shale band	14
Sandstone, flaggy calcareous; shale bands	2½

ORBICULOIDEA SHALE

	ft
Shale, red calcareous [5120 7297]; crinoid columnals; *Lingula* cf. *mytilloides*, *Orbiculoidea nitida*, *Ovatia bioni*, *Retispira sp. nov.*, *Donaldina sp.*, turreted gastropods indet., *Plagioglypta sp.*, *Aviculopecten* aff. *plicatus*, *Cardiomorpha sp.*, *Edmondia*?, *Polidevcia attenuata*, *Pteronites latus*, *Sanguinolites plicatus*, *S.* aff. *tricostatus*, *Schizodus axiniformis*, ostracods indet.	6
M.A.10	
Limestone, pink crinoidal; thin nodular algal layer 2 ft above base; rare marl bands with shell debris	14
Sandstone	3 to 4
?M.A.9	
Limestone, grey hard compact	2¾
Not exposed: much marly limestone debris	14
Limestone, red impure flaggy; much crushed shell debris and ostracods	2⅔
Limestone, reddish hard fine compact; impure marly bands; rare small ?algal nodules 9 ft above base	13
Marl and shale, red; disturbed	3
M.A.8	
Limestone, red massive; sandy towards base; abundant serpulids; affected by minor dextral strike-slip fault	3⅓
Sandstone, purplish; against fault in right bank [5121 7295]	—

Stack Cleugh

6-in NY 57 S.E. Measured by J. B. W. Day.
Shown graphically in Figs. 8 and 13. For map see Fig. 10.

LOWER BORDER GROUP

	ft
MAIN ALGAL BEDS	
Sandstone, massive, crop terminated by fault [5935 7481] ..	6
Sandstone, flaggy, shale bands ..	6
Sandstone, grey, calcaeous ..	⅔
Not exposed, shale debris near top	6
M.A.8	
Limestone, grey, hard, algal, oolitic at top	4½
Limestone, shaly; small algal nodules	1½
Sandstone, partly calcareous; included algal shale pellets ..	1½
Not exposed	—
BIRKY CLEUGH LIMESTONE	
Limestone, massive, sandy, repeated downstream by small fault [5927 7479] ..	1¾
Limestone; alga-encrusted shells	¼
Limestone	½
Not exposed	8
Limestone, yellow-weathering, sandy; microfossils	3
Limestone and calcareous shale	2
Algoolite, massive	1
Limestone, massive grey ..	1½
Sandstone	¾
Shale, sandy	2
Sandstone	¾
Cementstone, shaly [5918 7478]	2½
Shale	1
Sandstone, massive; forming waterfall	8
Shale	1
Not exposed	7
?M.A.4	
Limestone; crowded with small algal nodules; rare oolitic debris	2¼
Shale, sandy	5
Sandstone, massive shattered (forms waterfall)	25
Not exposed (limestone in neighbouring tributary)	3
M.A.2	
Limestone, oolitic nodular algal	3½
Algoolite; rare algal nodules	3
Shale, partly obscured	5
Sandstone	1⅔
Shale, sandy	1
Algoolite	½
Limestone, oolitic; crowded with comminuted alga-encrusted shell debris, yellow-weathering	½
Sandstone	¼
Shale, sandy	1¼
Sandstone, massive current-bedded	5
Shale, micaceous sandy	10 to 11
M.A.1	
Limestone, oolitic algal; thin band of alga-encrusted shells, associated with orthocone nautiloids 11 in above base	2
Cementstone, yellow-weathering banded	5½
BEWCASTLE BEDS	
Not exposed; shale debris ..	8
HIGH GRAINS SANDSTONE	
Sandstone, massive	6
Mudstone, shaly	8
Sandstone; massive and ochreous at base, flaggy at top	20 to 25
Shale	8
BROWN BAND	
Shale, brown-weathering, sandy ferruginous [5881 7469] ..	¼
Sandstone, flaggy; shale bands ..	6
Mudstone, calcareous	1½
Cementstone	1¼
Not exposed; shale debris ..	5
Sandstone	1
Shale	2
Sandstone, massive; forming waterfall and repeated by faulting	6
Shale, abundant ostracods and bivalves; repeated by faulting	8
Cementstone	2¼
Algoolite, algal nodules ..	¼
Limestone, weathering yellow, microfossiliferous, sandy ..	2¼
Mudstone, calcareous, thin limestone ribs	—
JUNCTION LIMESTONE	
Cementstone	1⅓

	ft
Mudstone, calcareous ..	2⅔
Cementstone	½
Shale, dark (probably represents fish band of Bull Cleugh) ..	½
Not exposed	8 to 9

WATERFALL SANDSTONE

Sandstone, massive	1
Fault [5863 7468] cuts out remainder of Waterfall Sandstone; section continues west of fault	?

PEEL LIMESTONE

Limestone, algal; *Garwoodia gregaria*, *Girvanella ducii* and abundant ostracods (loc. 15b)	4
Not exposed	4 to 5
Shale and mudstone	2
Limestone, soft, yellow-weathering	—

STACK CLEUGH OOLITE

Algoolite, hard; small algal nodules at top	⅓ to ⅔

	ft
Fireclay-mudstone; rare algal nodules	½
Mudstone, shaly sandy; rare limy nodules and flaggy bands ..	6

PLANTATION SIKE SANDSTONE

Sandstone	2
Limestone; ostracods	5 to 6
Not exposed	4
Sandstone, massive	4
Shale	6
Limestone, grey shaly ..	4½
Shale, carbonaceous; thin coal bands	¼
Shale, grey; rooty at top ..	1
Sandstone, massive	10
Shale, limestone nodules and thin sandstone bands	10
Shale, grey	4

RIGGHEAD LIMESTONE

Limestone, grey dolomitic [5838 7472]	1½
Fault	—

Whickhope Burn

6-in NY 68 N.E. Measured by D. H. Land.

UPPER BORDER GROUP

	ft
Sandstone, brown fine-grained [6863 8654]	4
Shale, grey and brown, silty ..	12
Not exposed	4
Shale, grey; including 1 ft of fine-grained, ochreous sandstone ..	9
Shale, grey partly silty; sandstone partings	6
Siltstone, grey calcareous fossiliferous; lens of argillaceous fossiliferous limestone containing coaly streaks; *Fenestella sp.*, *Punctospirifer scabricosta* and *Aviculopecten* cf. *interstitialis*	1
Shale, grey silty; many fine-grained sandstone partings above, plant debris below	11
Mudstone, grey calcareous; shaly at top; *Fenestella frutex*, '*Camarotoechia*' *sp.*, *Composita* cf. *ambigua*, *Aviculopecten interstitialis* and *Sanguinolites sp.* (loc. 87b)	8
Siltstone, grey, hard, slightly calcareous; forming a reef across the burn; prominent joints at 05°, some filled with calcite; subsidiary joints at 330° and 95°	2
Not exposed	6
Sandstone, thin-bedded flaggy; thin shale partings; shaly at top	10
Not exposed	about 22
Sandstone, brown-weathering, fine-grained slightly calcareous; crinoid columnals and *Aviculopecten* cf. *subconoideus;* strongly jointed at 10°, and 80° ..	2½
Shale, grey; including a 2-ft bed of fine-grained sandstone ..	8
MERLIN FAULT, cutting out ..	about 150
Sandstone forming upper post of Merlin Crags (not exposed in Whickhope Burn)	about 20
Not exposed; some shale debris in lower part	about 18
Shale, grey, rather silty micaceous; roots in upper part; rare thin sandstone partings	12

	ft
Sandstone, thin-bedded fine-grained; many thin shale partings; bedding planes irregular; flow-casts common	13
Sandstone, thick-bedded fine-grained locally false-bedded; rare thin shale partings; forms the lower post of Merlin Crags (for petrography see p. 219) . .	25
MERLIN CRAGS COAL; *not exposed* at old adits on left bank; only 8 in thick on right bank . .	? 1
Shale, partially exposed; rooty at top and bottom; fragmentary plants	7
Coal 5 in	½
Shale, grey; silty at top; roots and plant fragments; median parting of fine, flaggy sandstone 2ft	4½
Coal 1 in	—
Sandstone, fine-grained argillaceous	1
Shale, grey; many roots and plant fragments; top 1 ft not seen; silty, thin sandstone partings in lowest 2 ft	4½
Sandstone, flaggy fine-grained micaceous; silty shale partings	4
Shale, grey; silty at top; thin partings of fine-grained sandstone	6½
Shale, grey; plants and roots (partially exposed)	6
Sandstone, thin-bedded fine-grained; shaly at base . .	10
Shale, grey; rare thin sandstone partings	8

MERLIN LIMESTONE

	ft
Shale, grey; calcareous fossiliferous bands and lenticular, dark grey, brown-weathering, hard calcareous siltstone up to 4 ft thick; fossils include *Lithostrotion* cf. *martini*, *Fenestella frutex*, *Buxtonia sp. nov.*, '*Camarotoechia*' *sp.*, *Composita* cf. *ambigua*, *Echinoconchus punctatus*, *Punctospirifer scabricosta*, *Semiplanus sp. nov.*, *Spirifer sp.*, *Straparollus sp.*, *Aviculopecten sp.*, *Leiopteria divisa*, *Modiolus sp.*, *Myalina sp.*, *Naiadites crassus*, *Polidevcia attenuata*, *Sanguinolites sp.*, *Schizodus sp.*, *Streblochondria sp.*, orthocone, ostracods	7
Not exposed, including MERLIN ISLAND COAL, said to be about 2 ft thick, and formerly worked by an adit on the left bank . .	4
Sandstone, fine-grained micaceous rooty; large plant stems and roots at top	4
Sandstone, thin-bedded fine-grained micaceous; shaly in lower part; *Sanguinolites sp.*	6
Shale, grey; plants in upper part	3
Coal, shaly	⅓
Shale, carbonaceous	1¼
Shale, grey silty; roots; a few thin sandstone partings	4
Alternations of thin-bedded fine-grained micaceous sandstone and silty shale; some fragmentary plants and roots and rare bivalves including *Leiopteria divisa*, *Myalina sp.*, *Naiadites crassus* and *Sanguinolites sp.* . .	4
Shale, grey silty; fine-grained sandstone partings	3
Sandstone, fine-grained; partly thin-bedded, partly thick-bedded; rooty at top; lowest 22 in ferruginous, displaying box-weathering	8¼
Not exposed	14
Shale, grey silty micaceous; plant debris	8
Shale, grey; poorly exposed . .	4
Mudstone; *Modiolus* cf. *latus*, orthocone nautiloid and ostracods	1
Limestone, hard grey argillaceous; fossil debris	1
Mudstone, grey; includes a 1-in calcareous band containing *Buxtonia sp.*, '*Camarotoechia*' *sp.*, *Spirorbis sp.*, *Aviculopecten interstitialis*, *Myalina* cf. *pernoides* and *Polidevcia attenuata*	3
Shale, grey; plant debris . .	4
Not exposed, including WHICKHOPE COAL, formerly worked from adits on the left bank . .	3
Shale, rooty; *Modiolus latus* and ostracods at one horizon . .	2

	ft
Limestone, grey, hard, argillaceous; fossil debris	1
Shale, grey; fossil fragments and plant debris	4
Not exposed	10
Shale, grey locally carbonaceous; much plant debris; fossiliferous layers near base contain gastropod fragments; *Modiolus* cf. *latus* and ostracods [6814 8634]	6
Not exposed; ½-mile alluvial reach in burn; about 750	—
Sandstone (forming Bull Crag) [6694 8618], massive false-bedded fine-grained siliceous sparingly micaceous thin-bedded; thin shale partings near base; shale pebbles in lowest 2 ft	30
Shale, grey	1
Not exposed	2
Limestone, grey argillaceous; crinoid ossicles, fragments of productids and smooth spiriferids	¾
Not exposed	2½
Shale, calcareous, *Naiadites crassus* and *Schizodus sp.*	½
Siltstone, grey, hard, dolomitic; *Bellerophon* cf. *costatus*, *Leiopteria sp.* and *Polidevcia attenuata;* forms a cascade; (p. 218)	2
Mudstone, grey; ostracods	2
Coal, ½ in	—
Mudstone, grey rooty; becoming silty downwards	3
Not exposed	2
Shale, grey calcareous; fossiliferous layers including *Spirorbis sp.*, *Aviculopecten sp.*, *Naiadites crassus* (abundant), *Polidevcia attenuata* and *Schizodus* cf. *pentlandicus*	2
Coal, shaly 2 in	—
Shale, grey, roots in top 9 in; poorly exposed	9
Limestone, grey argillaceous; top crowded with fossils including *Bellerophon* sp., *Naiadites crassus, Polidevcia attenuata* and *Schizodus* cf. *pentlandicus;* (forms a cascade)	2
Not exposed	about 8
Sandstone, thin-bedded fine-grained; irregularly bedded, plant debris at top; calcareous with crinoid ossicles about the middle; rather shaly with silty shale partings in lower part; bivalves indet.	14
Not exposed	13
Sandstone, fine-grained; thin-bedded above, massive below	6
Not exposed	8
Sandstone, brown medium-grained calcareous; *Fenestella sp.*, *Echinoconchus* cf. *elegans*, *Punctospirifer scabricosta*, *Rugosochonetes sp.*, *Straparollus sp.* and *Schizodus sp.*	1¼
Limestone, grey hard massive argillaceous; sandy at base; fossils include crinoid columnals, *Fenestella sp.* and *Dielasma sp.*	2¼
Not exposed	about 70
Shale, grey, hard, calcareous; *Naiadites crassus*, *Sanguinolites* cf. *clavatus* and *Schizodus sp.*	1½
Not exposed, including BULL CRAG COAL (said to be about 2 ft thick)	about 4
Shale, grey; rare roots at the top	3
Not exposed	3
Sandstone, thin-bedded fine-grained; ripple marks and worm tubes at some horizons (for petrography see p. 218)	10
Mudstone, dark grey-brown silty calcareous; *Fenestella sp.*, trepostome bryozoa, *Buxtonia sp.*, *Linoproductus sp.*, *Aviculopecten* cf. *plicatus*, *Pteronites angustatus* and ostracods	2½
Not exposed	8½
Mudstone, grey silty micaceous; plant debris; lower part poorly exposed	7½
Siltstone, grey, hard, calcareous; shell debris	1½
Alternations of silty mudstone and fine-grained sandstone in beds ½ to 2 ft thick; some beds poorly exposed	about 10
Sandstone, grey, thin-bedded argillaceous slightly calcareous; crinoid columnals and *Fenestella sp.*, bedding planes very irregular; flow markings in places	12

	ft
Shale, grey micaceous; *Fenestella frutex;* poorly exposed	3
Sandstone, dark grey calcareous [6656 8614]	½
Prominent joints in the limestone 75 ft above the Bull Crag Coal run at 65° and 100°	—

Whitberry Burn

6-in NY 57 S.W. Measured by J. B. W. Day.
Shown graphically in Figs. 17 and 18.

MIDDLE BORDER GROUP

	ft
Sandstone, whitish fine- to medium-grained saccharoidal poorly micaceous; (topmost beds exposed below road bridge)	120
Not exposed; probably flaggy sandstone and shale	90
Limestone, weathering yellow, sandy [5199 7408]	3
Shale; sandstone bands; one thin limestone	14
Not exposed	20
Sandstone	1
Not exposed	3
Limestone, sandy	1
Sandstone	3
Shale, sandy; thin fireclay near top [5200 7409]	9
Sandstone; worm tracks on undersides of bedding planes	3
Shale, sandy at base	5
Limestone, grey	¾
Sandstone	8
Not exposed	4
Sandstone	2
Not exposed	5
Sandstone	6
Limestone	⅔
Shale	1½
Sandstone, flaggy	2
Shale	1½
Limestone, earthy	3
Sandstone, flaggy; shaly ribs	10
Limestone, grey-brown earthy [5201 7409]	18
Shale and sandstone	6
Limestone, grey earthy	2
Shale, sandy; sandstone bands	30
Shale, limy ribs; brachiopod debris	7
Sandstone, flaggy	5
Shale, calcareous; thin limestone at base	11¼
Shale, sandy; grading up into sandstone	4

SPADEADAM LIMESTONE (loc. 49b)

	ft
Limestone; *Composita ambigua, Echinoconchus punctatus* and *Aviculopecten sp.*	½
Shale, sandy; limy ribs	4
Sandstone, flaggy; grading down to sandy shale	10

WHITBERRY BAND (loc. 49a)

	ft
Shale, calcareous; abundant *Rugosochonetes cumbriensis*	5
Shale, sandy at base; rare *R. cumbriensis, Aviculopecten, Schuchertella sp., Ovatia bioni* and ostracods	7

LOWER BORDER GROUP

CAMBECK BEDS (loc. 33)

	ft
Not exposed	18
Sandstone, purplish massive; possibly affected by minor fault	35
Limestone, grey; hematitic at top	2½
Not exposed	½
Limestone, grey	½
Shale, grey, sandy	2½
Limestone, flaggy ?algal sparsely oolitic; sandy towards base	3⅔
Not exposed	12 to 18
Sandstone	6
Shale, sandy	7
Sandstone, massive	13
Shale, sandy	1⅔
Limestone	¾
Mudstone, shaly	2

HILLEND ALGAL BAND

	ft
Shale; algal nodules	1
Not exposed	4

	ft
Limestone, nodular algal; *Aphralysia sp.*, *Garwoodia sp.*, *Girvanella amplifurcata*, *G. wetheredii*, *Ortonella furcata*, *O. kershopensis*, *O. tenuissima* [5207 7408]	1¼
Not exposed	¾
Sandstone, whitish fine-grained rooty	4¼
Shale, grey	2¼
Limestone, earthy; shale band	1½
Sandstone, massive	18 to 20
Not exposed	16

SYRINGOTHYRIS LIMESTONE

	ft
Limestone, hard crystalline; abundant *Syringothyris exoleta* and *Schuchertella ambigua*; also '*Camarotoechia*' *sp.* in a 2-in band 1 ft above base [5208 7408, loc. 33]	3½
Mudstone, shaly; thin limestone ribs	5
Shale, calcareous; includes thin limestones	8 to 9
Limestone, grey hard	2
Sandstone, current-bedded	7
Shale, calcareous; abundant *Aviculopecten sp.*; also *Lingula* cf. *squamiformis*, *Schizodus sp.* and *Myalina sp.*	6
Limestone	3½
Shale; sandstone ribs at base	4½
Sandstone	6
Shale, sandy	12
Limestone, grey earthy	4 to 5
Shale, sandy	6

QUARRY SANDSTONE

	ft
Sandstone, massive current-bedded	7 to 8
Shale, sandy	8
Sandstone, flaggy; limestone bands	6
Alternating bands of shale and of limestone; crowded with myalinid bivalves	12

WHITERIGG SERPULA BAND

	ft
Limestone, flaggy sparsely oolitic	2
Mudstone	1
Sandstone	1
Mudstone	2
Sandstone	1
Mudstone, sandy	6
Shale, grey	2
Limestone, flaggy; bivalves and crinoid ossicles	4
Sandstone, slightly flaggy	7
Mudstone	12
Shale; limestone ribs containing *Antiquatonia teres* and *Orbiculoidea sp.* near top	14

BUTT LIMESTONE . .

	ft
Limestone, flaggy; abundant *Antiquatonia teres* and rarer *Chonetes*? s.l.	1
Shale, calcareous	2
Limestone, grey	1½
Sandstone; subordinate shale	6
Shale, sandy; sandstone ribs	6 to 7
Shale, dark; bivalves and ostracods	1

MAIDENWAY LIMESTONE

	ft
Limestone, grey earthy [5214 7406]	3
Sandstone, flaggy; thin shale at top	13
Shale, sandy	6
Limestone, calcite-veined	2
Sandstone, flaggy; rare serpulid tracks	15
Not exposed	20
Shale	4
Limestone; crowded with small productids	½
Shale	11
Not exposed	20 to 22

UPPER ANTIQUATONIA BAND

	ft
Shale, calcareous, limestone ribs; rare *A. teres*	8
Limestone, flaggy; abundant *A. teres*	4
Limestone, grey massive; rare brachiopods and ?serpulid tracks	6
Shale	7
Limestone; flaggy at top; abundant *A. teres*	3
Shale, grey	1
Shale, calcareous; rare brachiopods	3
Limestone	2
Not exposed	16
Mudstone, grey shaly	6
Shale, grey calcareous; *Spirorbis* and *Aviculopecten sp.*	1

	ft
Limestone [5219 7404]	1 to 2
BARRON'S PIKE SANDSTONE (for petrography see p. 213)	
Shale, sandy	5
Shale, sandy, and flaggy sandstone	8
Sandstone, massive; flaggy at top	18
Not exposed	6
Shale, dark calcareous; rare small ?algal nodules	1
Alternating bands of sandy shale and flaggy sandstone	14 to 15
Sandstone, whitish fine-grained massive	12
Sandstone, flaggy	2½
Not exposed; includes lower third of Barron's Pike Sandstone and all the Lower *Antiquatonia* Band, together with M.A.14	about 130
MAIN ALGAL BEDS	
Shale, very sandy, and flaggy sandstone	7
Not exposed; includes Woodhead Crag Sandstone	18
Sandstone	2
Shale; thin limestone ribs	14
M.A.12	
Limestone, grey; algal in patches [5226 7404]	1 to 2
Shale, calcareous; includes limestone ribs and two 6-in algal horizons 2 and 4 ft above base containing nodules up to 1 in diameter; algae include (loc. 24) *Bevocastria*?, *Garwoodia gregaria*, *Girvanella amplifurcata*, *G. ducii*, *G. wetheredii*, *Ortonella furcata*, *O. kershopensis*; the base of this bed may include M.A.11	7½
Sandstone, greyish white fine-grained	2
Shale, grey; limy ribs	4½
Sandstone, whitish rooty	3
Shale, grey sandy	10
Limestone, shaly	2
Shale, grey sandy (*Orbiculoidea* Shale position?)	8
?M.A.10	
Limestone, shaly; in thin beds	8
Limestone, nodular algal	1
Not exposed	7
Limestone	1
Shale, grey, very sandy; sandstone ribs at top	10
Limestone	1
Not exposed	20 to 25
M.A.9	
Limestone, grey	1
Not exposed	25 to 30
Sandstone, thin flaggy	2
?M.A.8	
Limestone, grey; bivalves	6 to 7
Sandstone, flaggy	4
Not exposed; some shale debris	25
BIRKY CLEUGH LIMESTONE	
Limestone, grey massive; rare algal pellets [5229 7398]	18 to 20

White Beck, south of Bushley Bank

6-in NY 57 S.E. Measured by J. B. W. Day.
Shown graphically in Fig. 13.

	ft
LOWER BORDER GROUP	
CAMBECK BEDS (loc. 29)	
LOWER ANTIQUATONIA BAND	
Limestone; *Antiquatonia teres* (debris only)	—
Shale, sandy	1
Not exposed	1 to 2
Limestone, grey calcite-veined; ostracods	1½
Shale, calcareous, alternating with cementstones in beds up to 1 ft thick; *A. teres* abundant, *Schuchertella* common; *Aviculopecten* rare; affected by small fault throwing down 3 ft to west	30 to 35
Cementstone, shaly; *A. teres* [5800 7316]	5½
Shale, calcareous; limestone ribs; poorly exposed	10 to 12
Limestone, flaggy; *A. teres* and *Schuchertella*	4
Shale, calcareous; *A. teres*	3⅓

	ft
Limestone, grey hard	1
Not exposed	7 to 8
Shale	2
Limestone, shaly; nodules at base; abundant ostracods and microfossils	6 to 7
Sandstone	½
Not exposed; sandy shale debris at top	3
Shale	1

MAIN ALGAL BEDS (loc. 27)

	ft
M.A.14	
Limestone, grey ?algal; poorly exposed [5791 7322]	2 to 3
Not exposed	6 to 8

WOODHEAD CRAG SANDSTONE

	ft
Sandstone, massive current-bedded (for petrography see p. 213)	10
Not exposed; limestone fragments in bank	10 to 12
M.A.13	
Limestone, grey sandy	3
Not exposed	1
Shale, calcareous; abundant '*Osagia*'-type algal nodules [5785 7326]	2
Limestone, grey shaly	1
Shale, sandy calcareous; forming waterfall	3½
Sandstone	1
Not exposed; sandy shale debris	6
M.A.12	
Limestone, grey; large algal nodules commonly encrusted with *Spirorbis* associated with ostracods; *Girvanella amplifurcata*, *G. ducii*, *Ortonella furcata* and *O. kershopensis*	3½ to 4
Shale, sandy; bivalve debris	3⅓
Limestone, grey sandy	1
Sandstone; plant debris	2
M.A.11	
Shale, grey; layer of algal nodules at base; *Garwoodia gregaria*, *Girvanella ducii*, *G. amplifurcata*, *G. magna*, *G. nicholsoni* and *Ortonella furcata*	2½
Limestone, nodular algal	½
Shale, crowded with large and small nodules, commonly *Spirorbis*-encrusted; top 6 in hard, oolitic; microfossils	1¼
Cementstone, shaly; layer of small algal nodules (3.0 to 6.0 cm) near top [5781 7330]	3⅓
Shale, sandy; carbonaceous at top	¾
Sandstone, massive current-bedded	10 to 11
Mudstone, grey sandy	4 to 5
Not exposed	7 to 8
Sandstone	1½
Limestone, hard (capping waterfall)	1

ORBICULOIDEA SHALE

	ft
Shale, sandy, calcareous; thin limestone ribs crowded with *Orbiculoidea sp.* and bivalves; rare algal nodules	9 to 10
Cementstone, shaly; microfossils and spines of *A. teres*	4½ to 5
Shale	1
Not exposed	3
M.A.10	
Limestone, sandy; microfossils	1½
Limestone, hard; top 2 ft shaly; abundant '*Osagia*'-type algal nodules [5775 7333]	5
Mudstone, shaly	1
Sandstone	1½
Algoolite	½ to ⅔
Shale, sandy	½
Sandstone	2⅔
Mudstone, grey shaly	1
Not exposed; shale debris	5
Sandstone, massive	2½
Shale, grey	2
Not exposed	5 to 6
M.A.9	
Limestone, grey massive [5769 7334]	2½
Not exposed	2
Limestone, grey massive	4
Mudstone, sandy	1½
Limestone, massive	1½
Limestone, grey compact; shaly at base; ostracods 1 ft from top	3
Sandstone, blue-grey calcareous	1½
Sandstone	1½
Not exposed	10
?M.A.8	
Limestone, grey	1
Sandstone, thin flaggy	¼
Not exposed	10 to 15

	ft
Sandstone, massive; forming waterfall; for petrography see p. 213	8 to 9
Shale, sandy	1
Sandstone, grey fine-grained massive	2½
Not exposed	1
BIRKY CLEUGH LIMESTONE	
Limestone, grey hard; no fossils seen	4½

A small fault repeats the lower 10 ft of the above section.

Appendix II

RECORDS OF BOREHOLE SECTIONS

Chapelburn No. 1 Bore

Surface 555 ft A.O.D. 6-in NY 66 S.W. Site [6091 6440] 850 yd N.N.E. of High Closegill. Drilled 1946 by Naworth Collieries Ltd. Cores examined by F. M. Trotter and L. S. O. Morris. Shown graphically in Fig. 28.

	Thickness		Depth	
	ft	in	ft	in
SUPERFICIAL DEPOSITS				
Boulder Clay	19	0	19	0
LOWER LIDDESDALE GROUP				
Fireclay	5	6	24	6
Shale, dark broken	6	6	31	0
Shale, dark micaceous	17	0	48	0
LOW TIPALT LIMESTONE				
Limestone, dark blue argillaceous; *Syringopora sp.*, near base	6	6	54	6
Shale, sandy; bottom 1 ft fireclay	4	6	59	0
Sandstone, soft; no core	3	9	62	9
Sandstone; shale band near base	6	0	68	9
Shale, dark sandy micaceous	8	6	77	3
Sandstone		9	78	0
Sandstone, with shale	4	6	82	6
Sandstone	4	0	86	6
Shale, sandy, and shaly sandstone	2	6	89	0
Shale		6	89	6
Shale, dark	6	6	96	0
Sandstone	5	0	101	0
Shale; sandstone bands	2	0	103	0
Sandstone, jointy	1	9	104	9
Sandstone	7	6	112	3
Sandstone, ironstone bands		6	112	9
Sandstone		6	113	3
Shale	8	6	121	9
Limestone	1	9	123	6
Sandstone; rootlets	1	9	125	3
Shale, very sandy micaceous, and shaly sandstone	4	0	129	3
Sandstone, light grey massive	26	0	155	3
Shale, sandy, and shaly sandstone	3	0	158	3
Sandstone, light grey	6	6	164	9
Shale, blue-black	1	6	166	3
Sandstone	2	3	168	6
Shale, fossiliferous from 192 ft	54	3	222	9
Limestone	1	3	224	0
Shale, calcareous	1	0	225	0
Limestone	1	0	226	0
Shale, calcareous	1	0	227	0
Sandstone, light grey; no core	13	0	240	0
Limestone, dark argillaceous	4	0	244	0
Shale, calcareous	2	0	246	0
DENTON MILL LIMESTONE				
Limestone, massive dark grey slightly crinoidal; trilobite near top	26	0	272	0
Limestone, dark fine-grained muddy	6	0	278	0
Limestone, calcareous shaly with shell bed	21	0	299	0
Ganister, rootlets; passing down into micaceous, light grey, massive sandstone with carbonaceous markings	31	0	330	0
Limestone		6	330	6
Shale, calcareous		6	331	0
Shale	1	0	332	0
Ganister seatearth, rootlets	4	0	336	0

	Thickness		Depth	
	ft	in	ft	in
Sandstone, micaceous, with carbonaceous markings	28	3	364	3
Shale, black	1	0	365	3
Ganister seatearth, rootlets; passing down into micaceous sandstone ..	6	0	371	3
Shale, sandy, and shaly sandstone; alternating ..	10	3	381	6
Sandstone, micaceous; carbonaceous markings	3	0	384	6
Fireclay	3	0	387	6
Shale, dark sandy; plant fragments	2	6	390	0
Sandstone, light grey micaceous flaggy; rootlets and carbonaceous markings	6	0	396	0
Sandstone, light grey ..	36	0	432	0
Sandstone, light grey; rootlets	2	0	434	0
'Grey beds'; alternations of sandy shale and shaly sandstone	37	0	471	0
Ganister; rootlets ..	6	6	477	6
Fireclay		6	478	0
Limestone; crinoidal ..		6	478	6
Shale, calcareous ..		6	479	0
Fireclay		6	479	6
'Grey beds'	1	0	480	6
Limestone, grey fine-grained; unfossiliferous	1	6	482	0
Fireclay	2	0	484	0
Shale, dark grey	16	0	500	0
Fireclay, poor sandy; 2-in ironstone	2	0	502	0
Shale; thin bands of sandstone	4	6	506	6
Shale, dark grey	1	0	507	6
Fireclay	2	0	509	6
Sandstone, siliceous ..	10	0	519	6
'Grey beds'	7	0	526	6
Ganister	9	6	536	0
Shale, sandy	14	0	550	0
Shale, dark grey fossiliferous calcareous	8	0	558	0
Limestone; *Lithostrotion sp.*	6	0	564	0
Shale, calcareous; *Lithostrotion sp.*	3	0	567	0
Limestone, fine grey ..	1	0	568	0
Limestone, shaly; *Lithostrotion sp.*	1	0	569	0
Ganister; rootlets ..	2	0	571	0
Sandstone, light grey siliceous	?6	0	?577	0
Shale, sandy ..	?9	0	586	0
Sandstone, light grey; micaceous partings				
Ganister, light grey ..		6	586	6
Shale, dark grey sandy; sandstone bands ..	1	6	588	0
Shale, grey; ironstone bands; 2-in limestone at 592 ft; *Syringopora* in bottom few inches ..	7	0	595	0
Limestone	3	0	598	0
Ganister	1	0	599	0
Sandstone, light grey ..	14	0	613	0
Fireclay	3	0	616	0
Seatearth, sandy	4	0	620	0
Ganister	5	0	625	0
Sandstone, shaly ..	5	0	630	0
'Grey beds'	3	0	633	0
Sandstone	2	0	635	0
Sandstone, shaly ..	6	0	641	0
Sandstone	6	0	647	0
'Grey beds'	9	0	656	0
Shale, fossiliferous calcareous		6	656	6
Limestone, light grey; unfossiliferous	1	6	658	0
Ganister	5	0	663	0
Sandstone, dark argillaceous	4	6	667	6
Sandstone, light grey ..	6	6	674	0
Sandstone, light grey shaly	6	6	680	6
Sandstone, light grey ..	24	0	704	6
Sandstone, light grey shaly	6	0	710	6
Shale, dark grey calcareous; fossiliferous ..	14	6	725	0
Limestone, shaly	1	0	726	0
Shale, dark grey calcareous, fossiliferous ..	6	0	732	0
Fireclay; plant debris ..	2	0	734	0
NAWORTH LIMESTONE				
Limestone, light grey, sparse crinoids ..	9	0	743	0
Fireclay, poor	2	0	745	0
Shale, dark grey sandy ..	3	0	748	0
Ganister	2	0	750	0
Sandstone, light grey ..	11	6	761	6
Sandstone, dark grey shaly	13	0	774	6
Shale; thin ½-in to 1-in bands of limestone; fossiliferous	14	6	789	0
Limestone; fossiliferous ..	4	6	793	6
Fireclay	6	6	800	0
Sandstone	1	6	801	6

	Thickness		Depth	
	ft	in	ft	in
Shale	2	0	803	6
Sandstone, light grey; carbonaceous layers	4	0	807	6
Shale, dark blue-black carbonaceous; traces of coal in thin layers; plants throughout, mostly *Calamites*, nodules of ironstone; practically a fireclay (position of Naworth Bryozoa Band)	22	0	829	6
UPPER BORDER GROUP				
CHAPELBURN COAL				
Coal	2	0	831	6
Fireclay	2	0	833	6
Limestone	1	0	834	6
Fireclay; plant debris	8	0	842	6

Chapelburn No. 2 Bore

Surface 513 ft A.O.D. 6-in NY 66 S.W. Site [6122 6486], 750 yd S.W. of Upper Denton. Drilled 1947–8 by N.C.B. Cores examined by A. W. Allen to 1010 ft. Shown graphically in Fig. 28 and Plate V.

	Thickness		Depth	
	ft	in	ft	in
SUPERFICIAL DEPOSITS				
Soil	1	0	1	0
Sand, gravel and boulders	16	0	17	0
LOWER LIDDESDALE GROUP				
Limestone	3	0	20	0
Shale, calcareous	1	6	21	0
Shale, calcareous; crinoidal	2	6	24	0
Shale, grey; calcareous bands	9	0	33	0
Shale, grey; ironstone bands	7	0	40	0
Shale, sandy micaceous	8	0	48	0
Sandstone, jointed	17	0	65	0
Shale	1	0	66	0
NAWORTH LIMESTONE				
Limestone, with lithostrotiontids and shells	16	0	82	0
Shale, calcareous crinoidal; corals	17	5	99	5
Ganister; shale bands; plant debris		10	100	3
Shale, black		9	101	0
Coal		6	101	6
Fireclay, black shaly	5	6	107	0
Sandstone, shaly, and sandy shale	5	0	112	0
Shale, black		6	112	6
Shale, sandy	3	6	116	0
Limestone, muddy; shell fragments	4	0	120	0
Shale, grading down to sandy shale	16	0	136	0
Sandstone, light grey	21	6	157	6
Limestone		3	157	9
NAWORTH BRYOZOA BAND				
Shale, calcareous; crinoids	2	3	160	6
Shale, black; plant remains	6	6	166	6
Shale, black; coaly layers		6	167	0
Shale, black; plant remains	1	0	168	0
UPPER BORDER GROUP				
CHAPELBURN COAL				
Coal 3 in		3	168	3
Fireclay, dark		9	169	0
Shale, dark micaceous	4	0	173	0
Sandstone; shaly at top	39	0	121	0
Shale, dark grey	2	0	214	0
Limestone, grey very sandy at top; large gastropods and crinoids	9	0	223	0
Shale, black; plant debris	3	0	226	0
Fireclay	3	0	229	0
Shale, sandy	6	0	235	0
Sandstone	8	0	243	0
Shale; sandy at top, finer towards base; ironstone nodules and bands	24	0	267	0
Sandstone	5	6	272	6
Shale; thick ironstone bands towards base	35	6	308	0
Limestone, unfossiliferous	5	0	313	0
Shale, calcareous	6	0	319	0
Limestone, shaly at top	9	0	328	0
Shale, black	2	0	330	0
Coal 4 in		4	330	4
Ganister	1	0	331	4
Fireclay	1	8	333	0
Shale, dark	5	6	338	6

	Thickness		Depth	
	ft	in	ft	in
Shale, calcareous	1	9	340	3
Limestone; rare shell fragments	4	9	345	0
THIRLWALL COAL				
Shale, carbonaceous; plant debris	3	6	348	6
Shale, sandy	1	6	350	0
Shale, calcareous	10	0	360	0
Limestone; calcareous shale bands	10	0	370	0
Fireclay, shaly	4	0	374	0
Shale, sandy	3	6	377	6
Shale, calcareous; shell fragments	5	6	383	0
Shale, sandy; ironstone bands and a coaly lens	1	6	384	6
Shale, calcareous; *Lingula sp.* and fish scales	1	6	386	0
Grit, shaly	12	0	398	0
Shale, black	2	0	400	0
Ganister	1	0	401	0
Grit, coarse; plant remains	21	3	422	3
Shale, black		3	422	6
Limestone; *Lithostrotion sp.*, large productids at 436 ft; shaly towards base	15	6	438	0
Shale, black; plant remains and coal traces	7	0	445	0
Fireclay	2	0	447	0
Shale, sandy	3	0	450	0
Sandstone; conglomeratic at base	18	0	468	0
Shale, dark; plant remains at top; sandy towards base	4	0	472	0
Limestone, grey; muddy at top, grading downwards into calcareous sandstone	26	0	498	0
Shale, sandy calcareous	17	6	515	6
Sandstone	10	6	526	0
Shale, sandy; plant remains; ironstone bands at base	5	0	531	0
Shale, calcareous; large productids	1	6	532	6
Shale, dark; ironstone bands		9	533	3
Limestone, sandy	3	9	537	0
Shale, dark; plant remains; grading down to sandy shale	15	0	552	0
Sandstone	1	0	553	0
Shale, calcareous; *Aviculopecten* cf. *tabulatus*, *Promytilus sp.*, *Soleniscus*?, gastropod fragments indet. and ostracods indet.	11	0	564	0
Sandstone; broken at base	7	6	571	6
No core: fault	9	0	580	6
Shale, dark; sandy towards base; fossiliferous at top	17	0	597	6
Sandstone; shaly at top	27	6	625	0
Shale, black calcareous; small productids		6	625	6
Limestone		3	625	9
Shale, dark calcareous; crinoids, *Rhabdomeson sp.*, '*Camarotoechia*' *sp.*, *Productus* (*Linoproductus*) fragment and *Spirifer sp.*	1	9	627	6
Sandstone, calcareous muddy	2	0	629	6
Shale, silty; plant remains; ironstone nodules and mussels at base	4	6	634	0
Siltstone, dark rubbly; plant remains		6	634	6
GAVELOCK OSTRACOD BAND				
Shale, irregularly bedded with ostracods		9	635	3
Shale, carbonaceous, with coalified plant remains	3	3	638	6
Shale, sandy and shaly sandstone	2	0	640	6
Sandstone, quartzose irony; plant remains	3	0	643	6
Shale, sandy; black at base	5	6	649	0
LEAHILL LIMESTONE				
Limestone, dark muddy; *Productus sp.*, fenestellids and lithostrotionids	10	0	659	0
Shale, black	3	0	662	0
Shale, (no core)	8	0	670	0
Fireclay, silty dark	4	0	674	0
Shale, sandy; carbonaceous bands	6	6	680	6
Sandstone, shaly	16	6	697	0
Shale, sandy; calcareous and irony at base	2	6	699	6
Shale, dark calcareous; pectinids and ostracods	4	6	704	0
Limestone, dark muddy; corals at base	3	0	707	0

	Thickness		Depth	
	ft	in	ft	in
Shale, calcareous; dark limestone ribs and shell fragments	6	6	713	6
APPLETREE LIMESTONE				
Limestone, impure	2	0	715	6
Limestone; large productids	4	6	720	0
Shale, calcareous; large productids (probably *Semiplanus sp. nov.*)	2	0	722	0
Shale, micaceous	4	0	726	0
Sandstone, micaceous	6	0	732	0
Shale; fireclay band; sandy towards base	3	6	735	6
Sandstone; gritty at top, shaly towards base	14	0	749	6
Shale, black		6	750	0
Shale, sandy; sandstone band at base	1	0	751	0
Shale, black laminated	2	0	753	0
Shale, calcareous shelly	1	0	754	0
FORSTER'S HILL and WILEY SIKE LIMESTONES				
Limestone, muddy; shaly towards base	26	0	780	0
Shale, calcareous; rare shell debris	6	0	786	0
Limestone, muddy; fossiliferous at top	3	0	789	0
Limestone, hard coralline; band of large productids	5	0	794	0
Limestone, hard grey	6	0	800	0
Limestone, fossiliferous; shaly at base	7	6	807	6
Shale, black; plant remains	3	6	811	0
Shale, dark sandy		9	811	9
SPY RIGG SANDSTONE				
Sandstone, massive and shaly; shale bands; ironstone band at 897½ ft; fireclay bands near base	114	9	926	6
Shale, black; rare plant remains	3	6	930	0
Limestone, shaly crinoidal shelly	5	0	935	0
Siltstone; plant remains	1	0	936	0
Shale, silty; rare shells	1	6	937	6
Sandstone; shale bands	13	6	951	0
Limestone, shaly; productoids, rhynchonellids and pectinids	4	6	955	6
Fireclay, dark rubbly	2	0	957	6
Mudstone, dark	1	0	958	6
Limestone; comminuted shell debris	1	6	960	0
Fireclay		6	960	6
Shale, silty micaceous; calcareous bands	2	6	963	0
Shale and limestone in bands; fossiliferous	2	0	965	0
?IRTHING SHELL BED				
Shale, black; merging downwards into muddy limestone; ?*Naiadites* near top	3	0	968	0
Shale, silty micaceous; laminated at base	5	0	973	0
Shale, and rubbly sandstone, fragmented	1	0	974	0
Fireclay	1	0	975	0
Shale, black; ironstone band at 976 ft 2 in, and *Lingula sp.* at 977 ft; fireclay at 986 ft; plant remains common	19	0	994	0
Sandstone, carbonaceous hard	1	3	995	3
Shale, black; plant remains		9	996	0
Sandstone, carbonaceous, and silty shale	4	0	1000	0
Shale, black laminated; plant remains and gastropods	10	0	1010	0
?MILLERHILL LIMESTONE				
Limestone	6	6	1016	6
Shale	28	0	1044	6
Limestone	2	6	1047	0
Shale	1	6	1048	6
Sandstone	20	6	1069	0

Spadeadam No. 1 (Middle Shield) Bore

Surface 675 ft A.O.D. 6-in NY 67 S.W. Site [6163 7040] 375 yd S. 36½° W of Middle Shield Cottage. Cored below 100 ft. Drilled 1956 by John Thom Ltd. Cores examined by R. H. Price. Abbreviated record. Shown graphically in Fig. 18.

	Thickness		Depth	
	ft	in	ft	in
SUPERFICIAL DEPOSITS				
Sandy soil	1	6	1	6
Sandy clay	4	6	6	0
Sandy clay and boulders ..	3	0	9	0
MIDDLE BORDER GROUP				
Sandstone with shale bands	7	0	16	0
Shale	2	6	18	6
Sandstone	2	0	20	6
Shale	3	6	24	0
DESOGLIN LIMESTONE				
Limestone	2	0	26	0
Shale	6	0	32	0
Shale, hard grey	3	0	35	0
Shale, soft grey	6	6	41	6
Sandstone, hard grey (?*Pitys primaeva* bed) ..	4	6	46	0
Shale, soft grey	4	6	50	6
Shale, hard blue	15	0	65	6
Sandstone, hard grey ..	24	6	90	0
Shale, blue	2	6	92	6
Shale, blue; coal traces ..		9	93	3
Shale, grey	6	9	100	0
Mudstone; *Naiadites crassus*, *Pteronites angustus*	5	3	105	3
Limestone		9	106	0
Alternation of shales and fossiliferous limestones; *Eocaudina sp.*, *Fenestella occulata*, *F. sp.*, trepostomatous polyzoan indet., *Antiquatonia teres*, *Composita ambigua*, *Linoproductus sp.* [*corrugatus* group], *Ovatia bioni*, *Punctospirifer scabricosta*, ?*Schuchertella ambigua*, *Syringothyris* cf. *exoleta*, *Leiopteria divisa*, *Pteronites angustatus*, *Streblochondria sp.* [colour banded], *Catastroboceras sp.*, ostracods (see Table II, p. 330)	28	0	134	0
JERRYCALF LIMESTONE				
Limestone; *Linoproductus sp.* [*corrugatus* group]	9	0	143	0
Shale; *Sanguinolites sp.* ..	10	0	153	0
Seatearth and limestone ..	3	0	156	0
Limestone and shale; *Lingula sp.*, *Linoproductus sp.*, *P. scabricosta*, *Myalina* cf. *pernoides*, *Sanguinolites* cf. *clavatus* ..	8	3	164	3
Fireclay		9	165	0
Sandstone and shale ..	41	8	206	8
Limestone	2	4	209	0
Shale; *Lingula sp.* ..	6	0	215	0
Limestone	1	8	216	8
Shales and limestone ..	3	4	220	0
Sandstone	17	0	237	0
Shales; thin limestones; *Lingula sp.*, *Polidevcia attenuata*, *Streblochondria sp.* and ostracods ..	12	6	249	6
DUMBLAR RIGG SANDSTONE				
Sandstone, massive ..	36	6	286	0
Shale and sandstone ..	7	10	293	10
Coal		2	294	0
Seatearth		6	294	6
Shales; *Paraconularia sp.*, *Lingula sp.*, *Bucanopsis sp.*	20	9	315	3
Sandstone	4	9	320	0
Shale; some sandstone; *Myalina sp.*, cf. *Naiadites crassus*	12	0	332	0
DUMBLAR RIGG LIMESTONE				
Limestone; *Dielasma*?, *Orbiculoidea* cf. *nitida* and *Aviculopecten sp.*	3	0	335	0
Shale; some sandstone ..	10	0	345	0
Sandstone	15	10	360	10
Limestone; shale band; algal in lower leaf ..	9	4	370	2
Shale	18	8	388	10
Sandstone	11	2	400	0

TABLE II

Ostracods from Spadeadam No. 1 (Middle Shield) Bore

Determinations by Dr. J. E. Robinson

Depth (ft)	113½	114	115	116	117	117½	122½	145	181	295	297	333	366
Acanthoscapha sp. nov.													X
Acratia fabaeformis Green						X		X					
A. sp. nov.	X												
Amphissites tricollina (Jones and Kirkby)							X						
Bairdia cf. *plebeia* Reuss						X		X					
B. cf. *regularis* Cooper		X		X	X	X							X
B. submucronata (J. and K.)							X						
B. sp. [close to *B. grahamensis* Harlton]	X												
Beyrichiopsis annectens J. and K.													X
B. fimbriata J. and K.									X	X	X		X
B. simplex J. and K.										X			
Carbonita fabulina (J. and K.)										X			
C. subangulata (J. and K.)										X			
C. wardiana (J. and K.) pars										X			
C. [*Argilloecia*] *sp. nov.*										X	X		
Cavellina cf. *longula* Cooper	X	X				X		X				X	
C. subpulchella Cooper					X					X			
C. sp.		X	X				X			X			X
Cyathus sp. nov.							X						X
Geisina sp.	X	X	X			X		X					X
Glyptopleura plicata (J. and K.)					X					X			
G. sp. nov. [*costata* group]		X	X	X	X	X		X	X				
G. sp.													X
G. [*Chesterella*] *sp.*	X												
Hollinella radiata (J. and K.)				X		X	X						X
Monoceratina antiqua (J. and K.)	X						X	X					X
M. sp. nov.										X			
Neokloedenellitina sp. nov.													X
Oliganiscus sp.		X		X									X
Paraparchites inornatus (McCoy)	X	X	X	X	X	X	X	X	X	X	X	X	X
'*Primitia*' *sp.*	X			X	X			X			X		
Pseudobythocypris cuneola (J. and K.)	X	X						X			X		X
Seminolites sp. nov.							X						X
Sulcella affiliata ((J. and K.)										X	X		
Youngiella sp.								X					X
New Genus [= *Namaia* Green 1963]										X	X		

Spadeadam No. 2 (Priorlancy) Bore

Surface 961 ft A.O.D. 6-in NY 57 S.E. Site [5910 7192] at N.W. corner of Priorlancyrigg Plantation. Drilled 1957 by John Thom Ltd. Cores examined by R. H. Price. Shown graphically in Fig. 17.

	Thickness		Depth	
	ft	in	ft	in
SUPERFICIAL DEPOSITS				
Subsoil	1	0	1	0
Boulder clay	81	0	82	0
LOWER BORDER GROUP				
CAMBECK BEDS				
Limestone bands	20	0	102	0
Shale, blue	3	0	105	0
Sandstone, brown	6	0	111	0
Fireclay	3	0	114	0
Shale, blue	14	0	128	0
No record	6	0	134	0
Limestone, grey fine-grained hard; sparse ostracods	2	0	136	0
Shale, grey; packed with *Lingula*, pectinids, *Edmondia* and large ostracods	1	0	137	0
HILLEND ALGAL BAND				
Limestone, grey fine-grained; small algal nodules, a few mussels and ostracods	4	10	141	10
Shale, grey; limy bands, ostracods, sparse plant fragments	2	2	144	0
Shale, grey; plants		3	144	3
Shale, grey sandy; a few ostracods at top	2	3	146	6
Sandstone, fine-grained flaggy; a shale parting		11	147	5
Shale, grey sandy; micaceous partings; planty at top, pectinids and other bivalves below	3	7	151	0
Limestone; grey fine-grained; sparse crinoid columnals and algal nodules, ostracods and other fossil debris	3	6	154	6
Shale, dark grey; few mussels and many ostracods	1	0	155	6
Shale, grey; plants	2	6	158	0
Sandstone, grey shaly; rooty at top, ?worm tubes below	3	4	161	4
Shale, grey sandy; sandstone partings and plant debris	2	10	164	2
Sandstone, light grey fine-grained hard	1	0	165	2
Shale, dark grey; small brachiopods, gastropods and abundant bivalves	4	10	170	0
Limestone, grey shaly; bivalves as above		9	170	9
Shale, grey; ?*Lingula*, ?*Naiadites*, abundant pectinids and ostracods	4	3	175	0
Shale, grey limy; limestone bands; crinoid columnals and spines, *A. teres*, *Schuchertella*, *Syringothyris*, a few pectinids and ostracods	4	0	179	0
SYRINGOTHYRIS LIMESTONE				
Limestone, grey; with abundant *Schuchertella* and *Syringothyris*	2	0	181	0
Limestone grey; abundant *A. teres*	2	0	183	0
Shale, grey limy; abundant ostracods; limestone bands; crinoids and *A. teres*	3	3	186	3
Limestone, shaly; *A. teres* and spines		7	186	10
Shale, dark grey; limestone bands; *Fenestella*, crinoids, *A. teres*, *Schuchertella*, horny brachiopods, bivalves and ostracods	6	2	193	0
Limestone, shaly; bivalves at top, ostracods throughout; *A. teres* and ?*Edmondia* at bottom	2	4	195	4
Shale, grey; with limestone bands; *A. teres*, *Lingula sp.*, *Orbiculoidea sp.*, *Myalina sp.*, pectinids and ostracods	3	8	199	0
Limestone, argillaceous; crystalline lenses; crin-				

	Thickness		Depth	
	ft	in	ft	in
oids and sparse bivalves at top	4	0	203	0
Shale, grey; plant debris		6	203	6
Limestone, grey shaly; rare *A. teres*; also *Lingula* and debris of bivalves including pectinids		6	204	0
Shale, grey micaceous		5	204	5
Sandstone, pale grey fine-grained hard micaceous flaggy; plant debris	1	7	206	0
Shale, grey sandy micaceous; sandstone bands; bivalves, ostracods and plant remains	4	6	210	6
Shale, dark grey; shelly and horny brachiopods, bivalves and ostracods	1	6	212	0
Limestone, dark grey argillaceous jointed; ostracods	2	0	214	0
Shale, dark grey; *Lingula*, bivalves and ostracods	1	0	215	0
Limestone, grey; a band of small algal nodules (*Garwoodia*) at 216 ft; bivalve fragments and ostracods	3	8	218	8
Shale, dark grey; *?Lingula*, bivalve fragments, ostracods and plants		8	219	4
Sandstone, pale grey fine-grained wispy bedded flaggy; roots at top and bivalve fragments in shale partings below	5	8	225	0
Shale, grey finely micaceous sandy; plant fragments and ?infilled worm tubes	1	0	226	0
Sandstone, grey fine-grained micaceous flaggy; rooty at top	4	4	230	4
Shale, grey finely micaceous; sparse plant debris; sun-cracks near base	1	6	231	10
Sandstone, grey flaggy micaceous; plant debris		5	232	3
Shale, grey; thin flaggy sandstone bands, ironstone nodules; bivalves and ostracods	3	2	235	5
Shale, dark grey; crinoids, bivalves and ostracods	2	1	237	6
Limestone, grey shaly crinoidal; *A. teres*, scaphopods, bivalves and ostracods	6	6	244	0
Shale, dark grey hard; ostracods		6	244	6
Limestone, grey shaly; band of small algal nodules; bivalve fragments, ostracods and plant debris	1	0	245	6
Shale, dark grey; abundant bivalves and ostracods		3	245	9
Shale, dark grey; calcareous bands; bivalves and ostracods		9	246	6
QUARRY SANDSTONE				
Sandstone, pale grey fine-grained; rooty at top	14	3	260	9
Sandstone, flaggy micaceous; plant debris and infilled worm tubes, alternating with finely micaceous planty shale containing *Lingula sp.*, at 262 ft	2	1	262	10
Shale, dark grey hard crinoidal; *Lingula sp.*, *?Bellerophon* and bivalve fragments	2	8	265	6
Shale, dark grey calcareous; thin limestone bands containing crinoid debris and abundant *A. teres*, bivalves and ostracods	2	6	268	0
Limestone, dark grey argillaceous hard; bands of crystalline limestone containing *A. teres* and ostracods; ?algal nodule and *Lingula sp.* at base; pyrite on joints	9	0	277	0
Shale, dark grey pyritic; *Lingula sp.*, *Myalina*-like bivalves, ostracods and plant debris	1	4	278	4
Limestone, dark grey; shale partings and *?Edmondia*	1	2	279	6
Shale, dark grey calcareous crinoidal; limestone				

	Thickness ft	in	Depth ft	in
bands; *Lingula sp.*, bivalves and ostracods	2	0	281	6
Limestone, dark grey shaly; crystalline bands, *A. teres*, bivalves and ostracods	1	6	286	0
Sandstone, pale grey fine-grained micaceous flaggy; worm markings near base	1	9	287	9
Shale, dark grey; micaceous bands and bivalves including pectinids	1	0	288	9
Sandstone, fine-grained flaggy micaceous		2	288	11
WHITERIGG SERPULA BAND				
Limestone, dark grey; shale partings containing *Lingula sp.*, bivalves, ostracods and plant debris	3	1	292	0
Limestone; algal nodules, *Serpula* and plant debris		6	292	6
Shale, dark grey calcareous; few ostracods and some *Serpula* and plant debris; a band of small algal nodules at base	1	3	293	9
Sandstone-seatearth, grey planty		3	294	0
Sandstone, grey fine-grained flaggy micaceous; shaly partings; small ironstone nodules in upper part	10	0	304	0
Mudstone, grey; ironstone nodules and thin partings of fine-grained, micaceous, flaggy sandstone; rooty at top, plant debris throughout, mussel debris at base	11	6	315	6
Limestone, dark grey; rare *A. teres*, scaphopods, bivalves and ostracods	5	6	321	0
Seatearth-sandstone, pale grey fine-grained micaceous	1	3	322	3
Sandstone, grey shaly		2	322	5
Mudstone, grey; rare ostracods		4	322	9
Seatearth, shaly grey		3	323	0
Sandstone, pale grey flaggy; rooty at top, shaly with worm tubes at base	3	2	326	2
Mudstone, dark grey; mussels; alternating with pale flaggy sandstone	2	4	328	6
Sandstone, pale grey argillaceous; shaly partings; rooty at top	2	6	331	0
Mudstone; thin sandstone partings; ironstone nodules; crinoid and bivalve debris at base	8	7	339	7
Sandstone, grey irony; bivalve debris at base		8	340	3
Mudstone, grey hard; *Orbiculoidea sp.*, bivalve debris and ostracods	2	9	343	0
Shale, grey crinoidal; limy bands, containing abundant *A. teres*, *Edmondia sp.* and ostracods	3	0	346	0
BUTT LIMESTONE				
Limestone, dark grey impure; abundant *A. teres*, scaphopods and ostracods	6	1	352	1
Shale; abundant *A. teres*, pectinids and ostracods	1	2	353	3
Limestone; top 4 in crystalline and crinoidal, earthy below; *Fenestella sp.*, *A. teres*, pectinids and worm markings	4	5	356	8
Shale; worm markings and bivalve debris		2	356	10
Limestone, grey impure crinoidal; with a crystalline nodule; *A. teres* and *Lingula sp.*	4	2	361	0
Sandstone, pale grey fine-grained; flaggy at top massive, micaceous below	[illegible]	0	369	0
Shale, grey sandy micaceous; thin sandstone partings and plants	2	1	371	1
Mudstone and shale, dark grey; calcareous in part; *A. teres*, *Lingula*, small gastropods, bivalve				

	Thickness		Depth	
	ft	in	ft	in
debris and one small *Orthoceras*	4	11	376	0
MAIDENWAY LIMESTONE				
Limestone, dark grey hard; knots of crystalline calcite containing crinoids and productid spines; a few *A. teres*; band of algal nodules at base	5	6	381	6
Shale, grey; slickensided at top, sandy micaceous below	1	0	382	6
Sandstone, pale grey fine-grained hard micaceous flaggy; sandy shale partings; plant debris ..	5	4	387	10
Shale, dark grey sandy; roots and plants ..	1	1	388	11
Sandstone, grey; partings of sandy shale; plant debris	3	1	392	0
Shale, grey sandy; grading down into argillaceous sandstone; *Stigmaria* and rootlets	1	2	393	2
Sandstone, pale grey fine-grained wispy bedded flaggy		10	394	0
Mudstone, grey; sandy bands; plant debris ..	1	0	395	0
Sandstone, flaggy; sandy shale bands; worm tubes	2	8	397	8
Shale, grey sandy; thin films of sandstone; sparse plant debris ..	1	8	399	4
Sandstone, pale grey fine-grained ripple-marked; shale films on bedding planes		6	399	10
Shale, grey sandy ..		2	400	0

Spadeadam No. 3 (Camp) Bore

Surface 700 ft A.O.D. 6-in NY 67 S.E. Site [6237 7030] 700 yd S.E. of Middle Shield Cottage. Drilled 1958 by C. Isler and Co. Ltd. Cores examined by D. H. Land, D. A. C. Mills and J. B. W. Day. Shown graphically in Plate V.

	Thickness		Depth	
	ft	in	ft	in
SUPERFICIAL DEPOSITS				
Soil, peaty	1	0	1	0
Boulder clay, dark grey and grey	30	0	31	0
UPPER BORDER GROUP				
CRYING CRAG SANDSTONE				
Layers of dark grey clay and iron-stained sandstone	4	0	35	0
Sandstone; iron-stained at top, pale grey thin-bedded fine- to medium-grained, with plant fragments, below	36	0	71	0
Sandstone, calcareous medium-grained; pyritized brachiopods and bivalves		4	71	4
Coal; trace	—	—	71	4
Mudstone, grey rooty ..	9	1	80	5
Mudstone, grey rooty; bivalves at top and base ..	4	1	84	6
Fireclay-mudstone, grey ..	6	3	90	9
Shale, grey silty; sandy bands; sparse plants and roots in upper part and a few brachiopods at base	27	3	118	0
Sandstone, grey thin-bedded fine-grained; thin calcareous bands containing brachiopods, crinoid ossicles, *Fenestella sp.* and drifted plant fragments ..	3	0	121	0
Limestone, grey sandy; carbonaceous plant fragments	1	0	122	0
Mudstone, grey shaly; ostracods; 2-in sandy limestone 1½ ft from top	4	6	126	6
Coal		2	126	8
Limestone, hard dark grey; small shell fragments ..		3	126	11
Mudstone, grey shaly rooty; ostracods and bivalves	5	1	132	0
Coal		1	132	1

	Thickness		Depth	
	ft	in	ft	in
Shale, rooty	1	7	133	0
Limestone, dark grey argillaceous; brachiopods and other shell fragments	1	4	135	0
Shale (no recovery)	3	0	138	0
Shale, rooty carbonaceous; thin coal films at top; pyritized mussels at base	3	8	141	8
Fireclay-mudstone, grey; much plant debris, coaly films and pyritized mussels and ostracods	1	0	142	8
Coal, shaly		4	143	0
Mudstone, grey; rooty at top, calcareous below; ostracods, bivalves, plant fragments	3	0	146	0
Fireclay, grey shaly		8	146	8
Coal		4	147	0
Fireclay, grey shaly	1	0	148	0
Limestone, argillaceous		6	148	6
Mudstone, grey; plant fragments in upper part, bivalves and ostracods in lower part	1	6	150	0
Fireclay, pale grey shaly; carbonaceous layers and plant debris	4	0	154	0
Mudstone, grey micaceous; plants	1	3	155	3
Sandstone and mudstone, banded, grey thin-bedded	1	9	157	0
Sandstone, fine-grained siliceous	1	4	158	4
Sandstone and mudstone, banded; sparse worm tubes in upper part	4	8	163	0
Shale, grey; sandy and silty bands; plant fragment, worm tracks	2	6	165	6
Sandstone, fine-grained; argillaceous at top, calcareous, with shell debris below; ankerite-pyrite veins	6	6	172	0
Mudstone, grey calcareous	1	0	173	0
Sandstone, fine-grained grey argillaceous; plant fragments	1	8	174	8
Mudstone, grey sandy micaceous; stick bryozoa and rare brachiopods	1	0	175	8
Shale, sandy micaceous; thin beds of argillaceous sandstone and worm tubes		7	176	3
Limestone, hard grey porcellanous		9	177	0
Mudstone, grey; plants and roots; thin sandy pyritic bands near base	3	0	180	0
Sandstone, greenish fine-grained argillaceous; with roots at top	3	0	183	0
Mudstone, grey; roots	1	0	184	0
Shale, grey finely micaceous striped; thin sandy partings; plant fragments	6	0	190	0
Sandstone, pale grey thin-bedded fine-grained micaceous; carbonized plant fragments and shell debris	10	0	200	0
Mudstone, dark grey finely micaceous; some bedding-planes crowded with ostracods; plant fragments	1	0	201	0
Sandstone, grey thin-bedded fine-grained; argillaceous except in top few inches; worm tubes and ankerite-pyrite veins	3	0	204	0
Shale, grey; thin coal streaks; roots, plants	5	0	209	0
Sandstone, pale grey thin-bedded and argillaceous in upper part, wispy-bedded below	6	0	215	0
Mudstone, hard grey and greenish brown slightly calcareous; sparse ostracods	1	0	216	0
Shale, grey		9	216	9

TINKLER CRAG SANDSTONE

Sandstone, grey thin-bedded fine-grained quartzose; a few micaceous partings; worm tubes; thin calcite-pyrite veins	12	9	229	6
Fault breccia of fine quartzose, pyritic sandstone; thin veins of calcite; rapid passage from overlying sandstone with junc-				

	Thickness		Depth	
	ft	in	ft	in
tion at about 45° from horizontal	1	6	231	0
Sandstone, fine-grained brown and grey; shale partings, in part pyritic; passing down to grey sandy shale (all in fault zone: core not complete)	4	0	235	0
Fault breccia of fine-grained, grey sandstone in sandy mudstone matrix; base crosses core at angle of 60° from horizontal	3	0	238	0
Sandstone, pale grey fine-grained thin-bedded; worm tubes and many irregular carbonaceous micaceous partings; partly brecciated near base	6	0	244	0
Shale, grey micaceous sandy calcareous; brachiopods, crinoid ossicles, bryozoa and plant fragments	2	0	246	0
Sandstone, grey thin-bedded fine-grained argillaceous; bedding-planes disturbed by worm tubes	2	0	248	0
Sandstone, pale grey calcareous siliceous thick-bedded fine-grained; thin veinlets of calcite; scattered small brachiopods and crinoid ossicles	7	0	255	0
Coal		1	255	1
Shale, dark greenish grey pyritic carbonaceous; ?ostracods		1	255	2
Limestone, dark grey hard argillaceous; sparse ostracods	1	4	256	6
Shale, grey calcareous; ostracod debris		9	257	3
Shale, grey sandy; plant debris and worm tubes at top	2	9	260	0
Mudstone, grey hard locally calcareous; calcite veins; shell debris, plant fragments; ostracods and fish debris at base	13	0	273	0
Limestone, grey argillaceous; plant fragments and ostracods	1	0	274	0
Shale, hard grey calcareous; ostracods and small bivalves	2	0	276	0
Mudstone, grey micaceous; roots	3	6	279	6
Sandstone, light grey very fine-grained siliceous; sparse roots	2	0	281	6
Mudstone, brownish grey hard calcareous; sparse small brachiopods near the base	1	6	283	0
Shale and mudstone, grey; plant fragments	3	8	286	8
Shale, brown; ostracods, fish debris and plant remains		1	286	9
Mudstone, grey rooty		3	287	0
Sandstone, thin-bedded fine-grained micaceous; carbonaceous-micaceous partings	1	0	288	0
Mudstone, grey; sandstone partings; plants, roots; small ironstone nodules; traces of blende and pyrite on joints	6	0	294	0
Sandstone, white fine-grained; micaceous partings	8	0	302	0
Shale, hard brownish grey; a thin layer containing fish scales near the top; poorly preserved *Lingula sp.*, fish and plant debris throughout, and ostracods at base	1	0	303	0
Shale, grey; carbonaceous at top; roots and plants below	1	0	304	0
Mudstone, grey; bivalves, ostracods, plant stems and roots	7	6	311	6
Fireclay-shale, grey; plant stems and roots		6	312	0
Shale, grey; plant stems and roots; ostracods throughout; a median 2-in bed containing small				

	Thickness		Depth	
	ft	in	ft	in
gastropods	1	0	313	0
Mudstone, hard grey; many ostracods, plant remains	1	0	314	0
Sandstone, grey fine-grained argillaceous; some slumping at top and bottom, sparse plant fragments	2	0	316	0
Shale, grey sandy micaceous; thin sandstone partings; worm tubes and sparse small brachiopods and bivalves	8	0	324	0
Sandstone, grey fine-grained calcareous argillaceous; thin sandy shale partings; worm tubes ..	5	0	329	0
Mudstone, grey shaly finely micaceous; scattered shell fragments; pyritic at base	1	0	330	0
Shale, carbonaceous ..		8	330	8
Fireclay-mudstone, grey ..		10	331	6
Mudstone, grey micaceous; occasional roots ..	2	6	334	0
(Probable fault at base: hade 30°)				
Sandstone, grey thin-bedded fine-grained shaly micaceous; worm tubes; pyritic shell fragments in lowest 1 in ..	3	0	337	0
Shale, carbonaceous ..	1	0	338	0
Coal		1	338	1
Mudstone, hard grey-green pyritic		1	338	2
Shale, greyish green; roots	2	10	341	0
Sandstone, grey massive fine-grained argillaceous: small ?worm tubes and with thin veins of carbonate and pyrite ..	8	0	349	0
Mudstone, grey slightly calcareous; bivalves and ostracods	1	3	350	3
Mudstone and sandy shale grey; roots	1	9	352	0
Sandstone, white massive fine-grained; thin micaceous partings; narrow veins of carbonate and pyrite	13	6	365	6
Shale, grey; occasional sandy bands	1	6	367	0
Mudstone, grey; ostracods	1	4	368	4
Coal		2	368	6
Mudstone, grey shaly, roots	1	6	370	0
Sandstone, thin-bedded shaly fine-grained ..	2	6	372	6
Fireclay-mudstone, grey ..	1	6	374	0
Shale, grey; thin sandy beds, worm tubes; sparse brachiopods	1	0	375	0
Sandstone, shaly micaceous; shale and ironstone partings; tubes and plant fragments ..	4	0	379	0
Mudstone, grey shaly; plants and roots ..	1	0	380	0
Shale, grey micaceous striped; thin sandstone partings; worm tubes throughout; sparse ironstone nodules; small bivalves near base ..	7	0	387	0
Shale, grey; small bivalves at top; calcareous, with abundant bryozoa and brachiopods below ..	4	0	391	0

KINGBRIDGE LIMESTONE

Limestone, argillaceous; large colonies of *Lithostrotion*	3	0	394	0
Limestone, hard argillaceous; brachiopods	2	0	396	0
Shale, calcareous; abundant bryozoa and brachiopods ..	5	0	401	0
Limestone, hard argillaceous; bryozoa and brachiopods	2	0	403	0

MIDDLE BORDER GROUP

Shale, calcareous; abundant bryozoa and brachiopods	6	0	409	0
Sandstone, massive fine-grained quartzose; occasional micaceous partings; shell and plant fragments near top	25	0	434	0
Siltstone, grey nodular ..	1	0	435	0
Sandstone, light grey wispy-bedded argillaceous ..	3	3	438	3
Siltstone, grey	1	0	439	3

	Thickness		Depth	
	ft	in	ft	in
Fireclay-mudstone, dark grey; carbonaceous layers; plants		9	440	0
Mudstone, grey sandy; pyritic nodules	6	0	446	0
Sandstone breccia (small fault)		4	446	4
Fireclay-mudstone, soft shaly; slickensided . .	3	8	450	0

Spadeadam No. 4 (Grey Mare Hill) Bore

Surface 940 ft A.O.D. 6-in NY 67 S.W. Site [6210 7395] Grey Mare Hill. Drilled 1958 by Le Grand, Sutcliffe and Gell, Ltd. (Cored below 85 ft). Cores examined by D. H. Land and D. A. C. Mills. For petrography see p. 216.

	Thickness		Depth	
	ft	in	ft	in
SUPERFICIAL DEPOSITS				
Boulder clay	85	0	85	0
MIDDLE BORDER GROUP				
Fireclay-mudstone, grey	2	0	87	0
Mudstone, greenish grey slightly sandy . .	2	0	89	0
Sandstone, fine greenish . .	5	0	94	0
Shale; hard sandy mudstone bands	16	0	110	0
Sandstone; mudstone partings	6	0	116	0
Mudstone	7	0	123	0
Mudstone, greenish-weathering	11	6	134	6
Sandstone, fine-grained . .	2	6	137	0
Mudstone, very sandy . .	2	0	139	0
Sandstone, fine-grained . .	1	0	140	0
Mudstone		6	140	6
Sandstone; fine at top, medium-grained towards base	17	11	158	5
Shale, greenish		4	158	9
Conglomerate; rounded and sub-angular pebbles up to ¼ in diameter, mostly of limestone and hard siltstone	1	6	160	3
Sandstone, medium- to coarse-grained	1	9	162	0
Mudstone, green sandy . .	3	0	165	0
No core	2	0	167	0
Sandstone; minute shale pellets	1	7	168	7
Mudstone; plant fragments	3	11	172	6
Sandstone		6	173	0
Mudstone	7	0	180	0
Shale and mudstone; sandstone bands	47	0	227	0
Sandstone; shale partings	16	0	243	0
Mudstone; sandy bands; sparse plant debris . .	50	6	293	6
Sandstone, fine micaceous	21	6	315	0
Mudstone	2	6	317	6
Sandstone	2	0	319	6
Mudstone, hard	1	6	321	0
Sandstone; argillaceous at top	5	2	326	2
Siltstone	6	0	332	2
Sandstone; slightly calcareous	1	0	333	2
Mudstone	1	10	335	0
Sandstone, greenish fine . .	2	0	337	0
Mudstone; pyritic nodules at base	5	6	342	6
Sandstone; some argillaceous bands	22	6	365	0
Mudstone, green sandy . .	4	0	369	0
Sandstone; shattered near base	13	4	382	4
No core	10	0	392	4
Sandstone, argillaceous . .	1	0	393	4
Mudstone; plant debris . .	4	2	397	6
Sandstone, hard micaceous	2	6	400	0

Appendix III

LIST OF GEOLOGICAL SURVEY PHOTOGRAPHS

Copies of these photographs are deposited in the Libraries of the Institute of Geological Sciences, Exhibition Road, London, S.W.7, and of the Institute's Northern England Office, Ring Road Halton, Leeds 15. All may be supplied as black and white prints or lantern slides at a standard tariff; those marked C as colour prints, and those marked T as 2 × 2-in colour transparencies.

LOWER BORDER GROUP

L 442	River Black Lyne, N.W. of Hole of Lyne [5430 7891]; steeply dipping Bewcastle Beds (top of Bogside Limestone).
L 443	Green's Burn, E. of Rinnion Hills [5660 6990]; *Syringothyris* Limestone and '*Derbyia*' Band.
L 444	Same locality as L 443; *Schuchertella ambigua* in the *Syringothyris* Limestone.
L 445 CT	Cam Beck, N.E. of Rinnion Hills [5665 7008]; "knobbly top" algal bed, near top of Cambeck Beds.
L 446 CT	Close-up of L 445, (Plate III A).
L 447	Ashy Cleugh [5744 7680]; faulted Ashy Cleugh Limestone.
L 448	Ashy Cleugh [574 768]; algoolite limestones with algal mudstone parting.
L 455	Birky Cleugh [5921 7538]; Main Algal Eleven: nodular algal mudstone.
L 456	Birky Cleugh, E. of High Grains [5885 7540]; Main Algal One overlying a *Serpula* reef.
L 457	Birky Cleugh [5896 7570]; Birky Cleugh Limestone and overlying beds (Plate III B).
L 463	River White Lyne, N.N.E. of Kaysbank [5119 7299]; Main Algal Eleven and Main Algal Twelve.
L 464 T	Same locality as L 463, Main Algal Eleven.
L 465 T	Same locality as L 463; Main Algal Eleven: algal nodule bed.
L 466 C	As L 465: a different part of same exposure. (Plate II A).
L 467	Same locality as L 463; Main Algal Eleven: *Collenia*-type algal growth. (Plate II B).
L 468	Same locality as L 463; Main Algal Twelve.

MIDDLE BORDER GROUP

L 469	Whitberry Burn [5203 7408]; Whitberry Band.
L 470	Same locality as L 469; bedding plane in Whitberry Band with *Rugosochonetes cumbriensis* and ostracods (Plate IV B).

UPPER BORDER GROUP

L 419 CT	Chirdon Burn at Seven Linns [6879 8021]; gorge and waterfall in Seven Linns Sandstone (Plate VI B).
L 420 T	Chirdon Burn at top of Seven Linns [6872 8024]; head of gorge in Seven Linns Sandstone.
L 421 CT	Quarry 750 yd N.W. of Lowe Bush [6495 7982]; sandstone.

L 423	T	Paddaburn Crags [640 789]; sandstone crags.
L 425	CT	Whickhope Burn 400 yd W. of Whickhope Lodge [6818 8640]; sandstones and shales above Whickhope Coal.
L 426	CT	As L 425: slightly different view.
L 427	CT	Merlin Crag [6834 8642]; sandstone crag.
L 428	T	Whickhope Burn 400 yd E.N.E. of Whickhope Lodge [6893 8650]; calcareous flags folded in monocline.
L 430		River Irthing, Gilsland Gorge [6351 6813]; Crammel Linn Sandstone, thickening southwards, with erosive base.
L 431		As L 430: closer view.
L 432	CT	River Irthing at Crammel Linn [641 697]; waterfall over Crammel Linn Sandstone.
L 433	CT	River Irthing N.E. of Gavelock Hill [6897 7264]; Appletree Limestone with small fault.
L 434	CT	River Irthing N.E. of Gavelock Hill [6894 7256]; limestone on thin coal just above Appletree Limestone.
L 435		River Irthing at Moss Catherine Waterfall [6853 7301]; waterfall over and potholes in Spy Rigg Sandstone.
L 436		River Irthing N. of Lampert [6867 7501]; Spy Rigg Fault: Lampert Sandstone (right) against Spy Hole Limestone and overlying strata.
L 437		As L 436: closer view.
L 438	T	River Irthing downstream from Sundayburn Linn [686 729]; gorge in Spy Rigg Sandstone and overlying beds.
L 439	CT	River Irthing at Sundayburn Linn [6847 7305]; gorge in Spy Rigg Sandstone (Plate VI A).
L 441		Spy Rigg [688 758]; Spy Rigg Sandstone with remanié blocks.
L 454		River Black Lyne opposite Oakshaw Ford Quarry [5111 7607]; Clattering Band showing colonies of *Lithostrotion* in position of growth.
L 471		As L 454: close-up.
L 472		As L 471: another view (Plate IV A).
L 473		Oakshaw Ford Quarry [5120 7605]; Oakshaw Limestone and Tuff.

LIDDESDALE GROUP

L 476	CT	Penton Linns [4320 7744]; anticline in Penton Limestone (close view of lower part of L 478).
L 477	CT	As L 476 (slightly different view).
L 478	CT	Penton Linns [4323 7748]; anticline in Penton Limestone, with Bridge Sandstone making sharp bluff on right, and Harelawhill Limestone cropping out in river downstream. (Frontispiece).
L 479		Penton Linns [4315 7742]; Bridge Sandstone on W. limb of Penton Anticline.
L 480		Penton Linns [4308 7742]; Harelawhill Limestone (right) striking downstream towards Blae Pot.
L 481		Penton Linns [4306 7740]; steeply dipping Harelawhill (right) and Gastropod limestones (Plate VII A).

MILLSTONE GRIT SERIES

L 475	T	Liddel Water at Blae Pot [4303 7724]; faulted Catsbit Limestone overlain by Blae Pot Limestone.

IGNEOUS ROCKS

L 473		Oakshaw Ford Quarry [5120 7605]; Oakshaw Limestone and Tuff.
L 474		Quarry at Kershope Bridge [501 833]; Kershopefoot Lava.

PLEISTOCENE AND RECENT

L 422	T	Hurtle Winter (from Craggy Shaw) [6680 8034]; ice-transported mass of rocks.
L 440	CT	River Irthing at confluence with Butter Burn [6785 7404]; alluvial flats and terraces (Plate VII B).

SCENERY

L 424	T	Panorama looking N. from Whickhope Nick [675 814]; forest-covered, mostly Upper Border Group country, with Peel Fell in distance.
L 449	CT	View of Bewcastle looking N.W. across valley of Kirk Beck: church and castle on a hill of glacial sand.
L 450	CT	View of Bewcastle looking E., with fells of Lower Border Group strata in background.
L 451	C	Bewcastle: another view looking east.
L 452	CT	Bewcastle: another view looking east.
L 453	T	Bewcastle: another view looking east.

The following photographs, listed above under stratigraphical headings, are also of scenic interest:

Upper Border Group: L 419 (Plate VI B), L 420, L 423, L 432, L 436, L 438 and L 439 (Plate VI A).
Liddesdale Group: L 478 (Frontispiece).
Millstone Grit Series: L 475.
Pleistocene and Recent: L 422 and L 440 (Plate VII B).

INDEX

Accessory minerals, 209–10
Agglomerate, 242–5
Agriculture, 2
Algae, 5, 16–17, 26, 43–5, 66, 82, 175–191; environmental significance of, 17, 175–6; growth forms, 11, 16–17, 175–6; lists of, 191–3; symbiotic association, 177
Algal limestones, lithology, 16–17, 43–5, 82, 177–9; sequence of, 19, 27, 44, 67, 83, 179–91
—— pellets, 16
—— reefs, 16
Algoolite, 16, 26, 178
ALLEN, A. W., 326
Alluvium, 3, 6, 261
Alston Block, 5, 11–12, 157
ANDERSON, F. W., iii, 46
ANDERSON, W., iii, 157
Andrew's Hill, 256
Anglo-Saxon settlement, 3
Anthraconauta tenuis, 3, 190, 226–7
Anticline, *see* Structure
Antiquatonia teres, 17–18, 66, 166–70, 190–4
Antonstown Burn, 25, 37, 63–4, 74
—— Fault, 25, 37, 63–4, 108, 133, 138, 232–3, 239–40, 268
Appletree Limestone, 126–7, 299, 302, 328, 340
Aquifers, 268
Archerbeck Beds, 158–9, 163
—— Borehole, 9, 11, 84, 105, 108, 114–15, 156–9, 161, 171, 223–4
—— Fault, 222, 224, 226–8, 233, 236
—— Ochre Bed, 223
Ashfell Sandstone, 211
Ashy Cleugh, 2, 25–6, 29, 37–8, 63, 200, 239, 270, 339
—— —— Limestone, 26–7, 29, 31, 35–6, 38, 40–1, 48, 183, 271, 285, 288, 307, 339
Ashycroft, 239
Askerton Fault, 79, 233, 239, 277
—— Low Park, 66
—— Park, 256
Athyris glabristria Zone, 16–17, 168
Atlantic Zone, 262
Atterson's Crook, 113
AVELINE, W. T., iii

Back Burn (Black Lyne), 121, 299
—— —— (Liddel), 115, 254
—— —— (Whickhope), 2, 102, 109–10, 139–42, 149, 204, 218, 257
Back Burn Fault, 109, 113, 163, 233, 236–7
Badds, 264
Baileyhead, 31
Bailey Hope Fault, 233, 235, 240
—— Water, 2, 31–2, 72, 122, 182, 200, 254
Bankhouses Limestone, 10, 157–8, 160
Banks Quarry, 23
Banna (Roman fort), 3, 266
Barn Pool, 69
Barren Crags, 137, 218, 267
BARRETT, B. H., and RICHEY, J. E., 3, 157‘ 222, 226
Barron's Pike, 74
—— —— Sandstone, 67–77, 213, 272, 283, 313, 321
Bartiestown, 253
Bartle's Burn, 90
Basal Permian Conglomerate, 4, 230
—— —— sands and breccias, 229
Basalt, 242, 244
Baxton Gill, 226–7
Beckhead-Binky Linn Fault, 72, 102, 143, 233, 240
Bellevue Fault, 56, 70, 233, 235, 237–8, 240
Belling Crags, 151–2
Bell's Braes, 203, 262
—— Burn, 253–4
Bendal Pool, 159
Bent Sike, 113
Bernician, 8–10
Bessiestown, 204
Bew Castle, 3, 267, 341
Bewcastle, 3, 26, 38–9, 255, 266, 268, 341; history of, 3; Roman fort at, 3, 266
——Anticline, 18, 20, 25, 66, 68, 72, 109, 232–3, 238–9
—— Banks, 38
—— Beds, 25–43; classification, 10; comparative sections, 29, 41; definition, 25; details, 26–43; distribution, 26; fossils, 25, 168, 192; generalized section, 27; limestones, 26, 181; lithology, 4, 25; palaeontology, 25, 168; petrography, 4, 25, 212; sandstones, 212; thickness, 15
—— Cross, 3, 94, 267
Binky Burn, 102, 143–4, 204, 257
—— Linn Limestone, 102
BINNEY, E. W., 226
Birdoswald Limestone Group, 8–10, 105
Birky Cleugh, 26, 39–42, 45–6, 60, 71, 74, 185, 201, 272, 339
—— —— Limestone, 43–4, 45–7, 57, 60–5, 184–6, 273, 282, 284, 315, 321, 323, 339
—— Grain, 137, 263

Birky Knowe, 118
Birrenswark Lavas, 15
Black Cleugh (Black Lyne), 248
—— —— (Chirdon), 137–8, 204, 265
—— —— (Kershope), 111
Blackcleugh Burn, 143, 204, 218, 273
—— —— Fault, 108, 233, 240
Black Cleugh Fault, 137, 233
—— —— Limestone, 138
—— Jack Sike, 141
—— Knors, 237
—— Knowe, 110, 135, 137
—— —— Fault, 233, 240
Blacklyne Bridge Limestone, 122, 297
Black Lyne Catchment, 2, 20, 28–36, 47–59, 70–2, 90, 109, 119–24, 254–5
Blacklyne House, 56, 70
Black Lyne (river), 18, 20–1, 28–31, 54, 70, 83, 90, 119–21, 181, 183, 199–201, 203, 215, 236, 238, 245–6, 254, 258, 293–9, 339
Black Murches Crag, 80
Blackpool Fault, 233
—— Gate Bridge, 123
Black Preston, 63
—— Sike, 104
—— Stantling, 101
—— —— Fault, 38, 75, 233, 240
Blae Pot, 162, 223
—— —— Limestone, 162, 223–4, 340
Blenkinsopp Boundary Fault, 125, 239
Blind Sike, 133–5, 265
Blowlowing Farm, 159
Boat Pool, 158
Bog bursts, 263
—— peat, 262
Bogside, 256, 289
—— Fault, 39, 233, 239, 263
—— Limestone, 10, 17, 21, 26–7, 29–31, 35–8, 169, 181, 272, 289, 294, 339
Bolton Fell, 263, 268
Bolt's Law, 138, 145
Border Group, 9, 15–155, 166–219
Borderrigg, 183, 255
Boreholes, records, 324–338; water supply, 268–9; *see* Archerbeck, Cairney Croft, Camp, Chapelburn Nos. 1 and 2, Greymare Hill, High Tipalt, Middle Shield, Midgeholme, Priorlancy, Riddings, Rowanburnhead, Thirlwall No. 1 and Wiley Sike bores
Bothrigg Burn, 20–3, 180–1, 200, 243, 276
Boulder clay, 3, 6, 251–7
Bracken Hill, 253, 267
Brackenhill Fault, 233, 237
—— Tower, 231
Brackenrow Sike, 64, 74
Brampton district, 8, 229, 235, 239
—— Memoir, 3
Bride's Gill, 38
Bridge Limestone, 158, 161–2, 291
—— Sandstone, 216, 219–20, 340
Broadford Beck, 66
Broadside, 254
Brock Knowe, 255
Brockram, 229
Broomhills, 231, 253
Broomy Linn, 142
Broomylinn, 104, 240, 263
'Brown Band', 26–7, 29, 40–2, 275, 315
Brunt Crag, 75
Bryozoa Band, 11; *see* Naworth Bryozoa Band
Bryozoan Limestones, 124, 309–10
Buccleuch Limestone, 157–8, 162, 175
Bull Cleugh, 39–42, 45–6, 61, 74, 275
—— Crag, 149–50, 318
—— —— Coal, 136, 265, 318
—— —— Sandstone, 136, 218, 318
—— Rigg, 121
Bullrigg Sandstone, 119, 217, 295
Bunter Sandstone, 229
Buried valley, 257
Burn Divot, 131, 256
Burns Beds, 114
BURNS, D., iii
Burnt Crags, 142
—— Tom, 104, 107, 152, 240, 247, 265
—— —— Crags, 94
Bushley Bank, 321
Butt Limestone, 71–2, 77, 79, 188, 278, 320, 333
Butter Burn, 2, 80, 100, 191, 201–2, 262, 341
Butterburn Flow, 262
Buxtonia sp. nov., 167, 171, 174, 190, 195, 198
Byreshield Grains, 146
—— Hill, 144

Cairn o' the Mount, 255
Cairney Croft Bore, 106, 130, 156–7, 160
Calcareous algae, *see* Algae
—— Division, 8, 10
—— tufa, 3, 42, 263
Caldwell Sike, 113
Callant Limestone, 11, 156, 158
CALVER, M. A., iii, 227
Cam Beck, 68, 71, 77–9, 94, 189, 20 230–1, 277–8, 339

Cam Beck–King Water Catchment, 2, 66, 77–9, 94–9, 124, 256
Cambeck Beds, 66–81; classification, 10; comparative sections, 71; definition, 66; details, 68–81; distribution, 68; fossils, 169, 193; generalized section, 67; limestones, 188; lithology, 4, 66; palaeontology, 169; petrography, 4, 66; sandstones, 213; thickness, 15; zonal position, 169
Camboglanna (Birdoswald), 3
Camp Bore, 105, 124, 172, 268, 334
Cannon Holes, 255
Canonbie Coalfield, 226, 266
Carbonaceous Division, 8, 10
Carboniferous Limestone Series, *see* Lower Carboniferous
——, Lower, *see* Lower Carboniferous
—— System, 4–228, classification, 10; palaeogeography, 4, 11; zonal divisions, 8–11; 16, 156, 167, 175, 222–3, 226; *see also* Lower Carboniferous
——, Upper, *see* Carboniferous System, Millstone Grit Series *and* Coal Measures
Carby Hill, 88
Carlisle Plain, 1
Carl Pool Limestone, 114
Carlyle Beds, 106, 114
Carter Fell, 46
—— —— Limestone, 45–6, 280
Carwinley Burn, 2, 205, 230, 253
Castle Beck, 106
Catchments, 2
Cat Cleugh, 161
—— Linns, 162, 205
—— Scar, 21, 24
—— —— Fault, 24
Catlowdy, 254
Catsbit Limestone, 9–10, 156–8, 162, 222–4, 340
Caud Beck, 2
Cementstone Group, 9–10, 15; *see* Lower Border Group
—— Limestone, 84, 96
Cementstone Series, 15; *see* Lower Border Group
Cementstones, 8–10; *see* Lower Border Group
CHALONER, W. G., 168, 170, 172
Chamot Hill, 91, 235
Channelbush Coal, 137–8, 265
—— Limestone, 137–8
—— Sike, 138, 265
Chapel Burn, 162–3, 205
Chapelburn Coal, 158, 326
Chapelburn No. 1 Bore, 324
—— No. 2 Bore, 127, 326
Chapeltown, 253, 267
CHAPMAN, S. B., 262
Chert, 107, 150
Chickensfield Sike, 114
Chirdon Burn, 2, 109–10, 138–9, 204, 263, 265, 280, 339
—— —— Catchment, 2, 135–9, 257
—— No. 1 Coal, 110, 139, 265, 280
—— No. 2 Coal, 110, 139, 265, 280
—— No. 1 Limestone, 139, 280
—— No. 2 Limestone, 110, 139, 280
Chonetes cumbriensis Band, 66, 82; *see* Whitberry Band
Christianbury Crag, 109, 123
Christy's Crags, sandstone of, 136–8, 145
—— Walls Coal, 145, 291
Classification, Carboniferous, 9–10
Clattering Band, 9–10, 17, 82–3, 90, 92, 105, 109, 119–20, 171, 203, 296, 311, 340
—— Ford, *see* Oakshaw Ford
Cleiothyridina glabristria, 166–9, 193
Cleughside, 29, 35
Clint's Sike, 70
Clinty Ford, 253
—— Sike, 88
Clock's Cleugh, 110, 138–9, 265
—— —— coals, 135, 138, 146, 265
—— Crags, 139
CLOUGH, C. T., iii, 3, 8, 108
Coal Burn, 135, 248, 265
—— Grains, 86–7, 201
—— Measures, 226–8; classification, 10; conditions of deposition, 6, 11; details, 227; distribution, 226; fossils, 227–8; lithology, 4–5, 226; thickness, 226; zonal position, 227
—— seams, 5, 12, 26, 82, 103, 106–7, 264–6; lowest, 26; resources, 3, 264–6; worked, 2, 106–7, 119–21, 126, 130–1, 135, 138, 147, 152, 159, 161, 264–6; *see also* Bull Crag, Channelbush, Chapelburn, Chirdon No. 1, Chirdon No. 2, Christy's Walls, Clock's Cleugh, Crow, Gair Burn, Grey's Crags, Hen Sike, Kilnholme, Lawston Linn, Lewisburn, Little Whickhope, Low Cranecleugh, Lower Netherhill, Merlin Crags, Merlin Island, Oakshaw, Oakwood, Penton, Plashetts, Reeker, Seven Linns, Shilburnhaugh, Solport, Thirlwall, Throssburn Foot, Upper Netherhill, Waverley, Whickhope and Whickhopenick Sike coals

Colin Bank, 63
Collenia, 17, 62–3, 175, 339
Collering Sandstone, 125–6, 217, 300
Common Flat, 289
—— —— Limestone, 18, 20–1, 23, 25, 181, 289, 295
Contemporaneous downwarping, 12, 93, 108, 232
Contorted bedding, 74, 82, 107, 110
Coom Rigg, 139
—— —— Moss, 262
Coomsdon Burn, 45–6, 280
Cooper's Burn, 253–4
Corby Linn, 110
Corner House Inn, 32
Cornet Limestone, 158
Correlation, 8–11, 105, 156–7, 222, 229
Cow Crags, 134
Crabtree Pool, 115, 304–5
Crag Burn, 117
Craggy Burn, 150
—— Cleugh, 87, 111–12, 243
—— Shaw, 137
Craig Burn, 95
Craig, G. Y., 11
Craiggy Ford, 90
Craighill Sandstone Group, 8–10, 105
Crammel Burn, 126
—— Linn, 299, 340
—— ——Sandstone, 125–6, 217, 301, 340
Cranecleugh Burn, 149, 204; *see* Whickhope Burn
Cravenoceras leion, 11, 222
Crew Burn, 25, 37, 45, 64, 74, 281
—— Crag, 75
—— Fell, 268
Crook, 25, 200
Crookall, R., 227
Crook Bridge, 59
—— Burn, 2, 29, 35, 45–7, 68, 71–2, 183, 200–1, 235, 283
—— Gill, 123, 203
Crookholm, 227
Cross, Bewcastle, 3, 94, 267
Crossgreens, 266
Cross Sike, 148
Crossy Cleugh, 100
Crow Coal, 120–1
Crowwood Pool, 113
Crubinshill Sike, 29, 31, 33, 45–8, 187, 200, 235
Crying Crag, 125
—— —— Sandstone, 124–5, 334
Cuddy's Burn, 46, 50, 200
—— Fault, 50, 72, 233, 237
Cumbrian Block, 5, 11
Cumcrook Limestone, 108–9, 115, 120–1, 124, 295, 305, 309
—— Wood, 119
Currick Sike, 249
Cyclic sedimentation, 6, 15, 66, 107, 156
C_1 Zone, 168
C_2 Zone, 168–9

Dappleymoor Fault, 109, 120–1, 233, 236, 295, 297, 299
Davison's Crags, 134
Davy's Round, 70
Day, J. B. W., iii, xi, 334
Denton Mill Limestone, 156, 158–60, 324
Desoglin Limestone, 84, 96–7, 329
Dhu Bog, 256
Dinantian, 9; *see* Lower Carboniferous
Dinwoodie Beds, 11, 105–6, 116, 156, 158, 160, 175
District, definition of, 1
Divide, water, 258
Dixon, E. E. L., 229, 251
Dobby's Sike, 38
Dodgsontown, 120
—— Ford, 297
Dog Pool, 24
Dolerite, 244–5
Dormansteads, 253
Dormont Pool, 163, 205
Dorryfield, 253
Dove Crags, 87
Drainage channels, glacial, 252–7
—— pattern, 258–61; initiation, 6
Draught Sike, 254
Drift, 251–63; sequence, 251
Drowned Sike, 103
Drumlins, 254–6
Dumblar Rigg, 99
—— —— Limestone, 83, 99, 329
—— —— Sandstone, 95, 101, 216, 329
Dun Limestone, 8–10
Dunk Pool Limestone, 113–14
Durham Millstone Grit, 11
Dykes, 6, 113, 242, 246–50
Dyscritella nana, 99, 105, 167, 194
D Zone, 156–7, 175

Earth-movements, 6, 232–41
Earthwork Sandstone, 27, 29, 31, 37–42, 266, 271, 307
East Christianbury Fault, 233, 240
East Skelton Fault, 70, 233, 235, 237
Easton, 253
Eastwood, T., iii, xi

Eden, Lake, 261
Edriasteroids, 172
Elf Kirk Fault, 233
Ellery Grain, 77
—— Sike, 2, 20–2, 168, 179–80, 200
—— —— Limestone, 18, 21–2, 25, 180, 286
English Kershope, 26, 28, 200
Eomarginifera setosa, 167, 175
Erratics, 251, 253, 255
Eskers, 252–5, 267
Esk, River, 261
Euphemites, 169, 192
E Zone, base of, 175, 222

Fairies Sike, 28, 200
Farloan Sike, 121, 203, 299
Faults, 232–40; contemporaneous with sedimentation, 12, 108, 232; *see also* Antonstown, Archerbeck, Askerton, Bailey Hope, Beckhead–Binky Linn, Bellevue, Blackcleugh Burn, Black Cleugh, Black Knowe, Blackpool, Black Stantling, Blenkinsopp Boundary, Bogside, Brackenhill, Cat Scar, Cuddy's, Dappleymoor, East Christianbury, East Skelton, Elf Kirk, Friarhillgate, Gill Pike North, Gill Pike South, Gilsland, Goat Island – Lyne, Harrett's Linn, 'Hilton', Hilltop, Hogwash, Hole of Lyne, Horse Head, Kaysbank, Kershope, Kershopefoot, Kyloe, Lampert, Low Park, Luckens, Lynedale, Lyneholmeford, Merlin, Mewsgate, New House, North Upper Denton, Pallyards, Parkhouse, Pennine, Penton Linns, Pikeburn, Reeker Pike, Rough Grain, Saughy, Shopford, Show Burn, Spy Rigg, Todholes, Waterhead, Watleyhirst, Whickhope Linn, Whickhope Nick, White Preston and Wythes faults
Fawcettlees, 39
Fellend, 89
Fell Sandstone Group, 8–10, 12, 46, 208–11;
see also Middle Border Group
Five Yard Limestone, 158
Flood-plains, alluvial, 6, 261
Floweryhirst Bridge, 74
Fluctaria sp., 167, 198
Flush Crags, 133
Forests, 2–3
Forster's Hill Limestone, 299, 302, 328
Forster's Hill Sike, 299
Fossils, 166-207, 227–8; list of, 191–9; selected localities, 199–205
Foulbog Sike, 80
Fountains Sike, 37
Four Fathom Limestone, 158
FOWLER, A., 8–10, 108
Fowlsnest Pool, 114
Foxhole Sike, 152
FRANCIS, E. H., iii
Francis Ford, 158
FRANKS, J., 262–3
Friarhillgate Fault, 233, 237

Gair Burn, 110, 131–3, 203
—— —— Coal, 132, 265
GARWOOD, E. J., 3, 8, 15–17, 25, 46, 60, 66, 77, 84, 105, 166, 168–9
Gastrioceras subcrenatum, 11, 222
Gastropod Limestone, 158, 161–3, 290, 340
Gate Grain, 75–6, 94, 201
Gavelock Band, 126, 301, 327
—— Hill, 264
GEORGE, T. N., 167
GIBSONE, E., 226
Gigantoproductus maximus, 167, 175, 198
Gillalees Beacon Plantation, 77
—— Beck, 77
—— Farm, 66, 188
—— Scrogs, 77
Gill Hassock, 257
Gillhead, 123
Gill Pike, 110, 136, 141, 154
—— —— North Fault, 154, 233
—— —— South Fault, 233
—— Sike, 104
Gilsland Fault Belt, 109, 233, 239
—— Gorge, 106, 109, 125–6, 259–61, 340
—— -Kirkcambeck kame-train, 252–3, 256
Glacial deposits, 6, 251–7; sand and gravel, 6, 252–6, 267
Glaciation, 6, 251
Glencartholm Volcanic Beds, 84, 88, 107, 245
Glen Dhu, 246
Glendhu Hill, 87, 235
Goat Island, 115–16, 237
—— —— Limestone, 11, 105–6, 109, 115–16, 156, 160, 175, 303
—— —— -Lyne Thrust, 109, 115–16, 160, 233, 236, 306
Golden Cleugh, 88, 112, 202
GOODCHILD, J. G., iii

Goose Sike, 123
Gorcock, 161
Gosling Sike, 131
GRAHAM, W. E., iii
Great Limestone, 9–11, 156, 158, 175, 222–3
Greengate Well Limestone, 158, 161
Green Grove Sandstone, 125, 216, 300
Greenhead, 156–7
Greenhead Bankhouses Limestone, 157–8, 164
Greenhill Sike, 126
Greenholme, 20, 24
Greenmeath Sike, 257
Green's Burn, 2, 41, 62, 77–8, 94, 183, 200, 202, 339
Greymare Hill Bore, 100, 216, 268, 338
Grey Mare's Crags, 136, 141, 153–4
Grey's Crags, 136, 151
—— —— Coal, 148, 151–2, 265
—— —— Sandstone, 136, 219
Ground water, 268–9
Gulley Sike, 143, 240
Gypsum and anhydrite, 230, 266

Hagg Beck, 118–19, 160, 204, 253, 264
Haggbeck Cottage, 119
Hagg Sike, 252
Hagling Burn, 115, 236, 254
Haithwaite, 252
Hallees, 253
Hall Hills, 255
Hallsford, 160
Haltwhistle Burn, 259–60
Hangingstone Crag, 94
Harden Burn, 46
Harelawhill Limestone, 156, 158, 161–3, 289, 340
Harepark Cleugh, 63–4, 74
Harrett's Linn Fault, 87, 108, 232–3, 238, 240
HARRISON, R. K., iii
Harry's Sike, 123, 245
Hazel Gill, 2, 80
Hazelgill Crag, 74
Heather Sike, 248
Hell's Bottom, 80
Hen Hill, 79
Hennel Cleugh, 39, 40
—— —— Sandstone, 27, 38–42, 212, 214, 288
Hen Sike, 149
—— —— Coal, 149, 265
Hercynian Orogeny, 232
Hether Burn, 230
High Grains, 29, 200, 256
—— —— Sandstone, 26–7, 29, 33, 38, 40–2, 61, 275, 285, 306, 315
—— —— Waste, 80
—— Green Dyke, 246
—— Long House, 103, 247
—— Mossthorn, 255
—— Onset, 25
—— Parkfoot, 93
Highstead Ash, 97
High Tipalt, 161
—— —— Bore, 130, 158
Hill Cleugh, 37, 71, 74
Hillend Algal Band, 67–8, 71, 73–4, 79, 189, 277–8, 312, 319, 331
Hill peat, 3, 262
'Hillton' Fault, 236
Hilltop Fault, 163, 233, 236
Hilton Plant Beds, 229
Hinge-lines, 12, 108, 232
Hirstead Sike, 204
Hogg Limestone, 108
Hog Wash, 161–2
Hogwash Fault, 162
Holborn Anticline, 239
Holehead, 122, 254
Hole of Lyne, 20, 30, 182, 199
—— —— —— Fault, 20, 30–1, 57, 233, 237–8, 240
Hollin Cleugh, 54, 200
Holmehead, 20–1, 29–31, 199–200, 293
—— Limestone, 27, 29–30, 36–7, 271, 293, 307
Hope House Limestone, 139
Hope's House, 253
Horse Head, 142, 256
—— —— Fault, 140–1, 233, 240
HOWELL, H. H., iii
Hudd's Hole, 252
Huddshole Ford, 204
HULL, J. H., 9
Humble Burn, 2, 142–4
—— Hill, 142
—— —— Anticline, 142, 233, 240
Hurtlewinter, 256, 341

Igneous rocks, 4, 242–50
Intrusions, 4, 242–50
Irregularly contorted beds, 74, 82, 107, 110
'Irthalt', River, 259–61
Irthing Catchment, 2, 80, 100–2, 125–35, 160–4,
—— Head, 133

Irthing, River, 2, 109, 125–7, 203, 217–18, 249, 258–64, 299, 301, 340
—— Shell-Bed, 109, 127–8, 300, 328
—— Valley, 268
'Irthwhistle', River, 259–60

Jamie's Hill Sike, 124
—— Sike, 131, 204
Jenkinstown, 118
Jerrycalf Limestone, 83, 100, 329
—— Sike, 100
Jew Limestone, 158
Job's Cleugh, 24
Jockie's Sike, 226–7
Jock's Pike, 149
—— Pool Limestone, 110, 136, 157
Johnny's Crags, 134
JOHNSON, G. A. L., 3, 9, 157, 164, 222
JONES, T. R. and KIRKBY, J. W., 169
Junction Limestone, 27, 29, 37, 41, 42, 183, 270, 285, 306, 315

Kames, 252, 267
Kaysbank, 310
—— Fault, 59, 70, 233, 238, 306
Keld Sike, 26, 200
Kennel Crags, 133
Kershope Bridge, 88, 108, 340
—— Burn, 68–9, 87–9, 110–13, 201–2
—— —— Catchment, 2, 26–8, 68, 84–9, 108, 110–13, 252
—— Fault, 87–8, 110–11, 233–5
Kershopefoot, 68, 88, 113
—— Basalt, 84, 87–8, 236, 242, 244, 340
—— Cleugh, 88
—— Fault, 112–13, 233, 235–6
—— Limestone, 68
Kettle Beck, 77
—— Hall, 254
—— Sike, 77
Keuper Marl, 229
Kilnholme, 161–2, 265
—— Coals, 157–8, 222, 265
—— Syncline, 236
Kiln Pool, 117
—— —— Limestone, 115–17, 122, 303–4
—— Sike, 113–14, 246
Kilnstown, 255
Kingbridge Ford, 95–6
—— Limestone, 83–4, 95–9, 105, 124, 337
Kingfield House, 163
King Water, 79, 83–4, 95–8, 100, 109, 124, 202–3, 248, 258–60
Kingwater Beds, 84, 105
—— Limestones, 8, 10, 84
Kinmont Limestone, 11, 158
Kirk Beck, 2, 18, 20–3, 26, 29, 38–41, 74, 181, 200, 212, 288, 341
Kirkbeckstown, 20
Kirk Burn, 2, 46, 47, 70, 200
Kirkcambeck, 68, 109, 231, 256, 267
Kirklinton Sandstone, 4, 6, 229–30
Kitchen Sike, 113–14, 202
Kittybeck, 39
Kitty Beck Limestone, 27, 29–30, 35–9, 182, 272, 285, 293, 307
Knowe, 31
Kyloe Fault, 233, 240
—— Slack Sike, 146

Lamellibranch Limestone, 84, 96
Lampert, 109, 203, 262
—— Fault, 128, 233, 239
—— Sandstone, 129, 217, 300, 340
Lancy's Cleugh, 70, 246
LAND, D. H., iii, xi, 334, 338
Lanercost Limestone, 10, 106, 115, 125, 304–5, 308
Langholm Memoir, 1
—— Sheet, 1
Langley Burn, 2, 32–3
Larey Sike, 131
Larriston Burn, 46
—— Fells, 46
Lava, 242, 244
Lawston Limestone, 108, 113, 115
—— Linn Coal, 119
Lazy Knowe Fault, 235
Leagair Quarry, 89, 114, 203
Leahill Limestone, 109, 126, 171, 299, 301, 327
Leaning Stone Crags, 136
Leaps Flosh, 253
LEBOUR, G. A., 8, 10, 246
Lees Hill, 256
Lemmington Anticline, 239
Lewis Burn, 108, 152, 213–14, 247, 265
—— —— Catchment, 2, 80, 103–4, 152–4, 257
Lewisburn Coals, 10
Lewis Burn–Troughend Dyke, 28, 70, 80, 103, 233, 242, 246–7
Liddel Catchment, 2, 68–9, 113–15, 159–64, 252
—— Water, 2–3, 69, 108, 113, 156–62, 197, 202, 204–5, 219, 224, 226–7, 236, 246, 261, 265, 289, 340

Liddesdale, 8
—— Group, 156–65; classification, 10; comparative sections, 158; conditions of deposition, 4, 11–12; correlation, 10, 156–7; definition, 9–11, 156; details, 159–65; distribution, 156; fossils, 175, 197–9; lithology, 4, 156; palaeogeography, 11; palaeontology, 175; petrography, 4, 156; sandstones, 208, 219; thickness, 156; zonal position, 156, 167, 175
Limestone Coal Group, 222
Limestones 15–16, 26, 82, 106–7, 156, 177–91; algal, 16, 177–91; *see also* Appletree, Ashy Cleugh, Bankhouses, Binky Linn, Birky Cleugh, Black Cleugh, Blacklyne Bridge, Blae Pot, Bogside, Bridge, Bryozoan, Buccleuch, Butt, Callant, Carl Pool, Carter Fell, Catsbit, Cementstone, Channelbush, Chirdon No. 1, Chirdon No. 2, Common Flat, Cornet, Cumcrook, Denton Mill, Desoglin, Dumblar Rigg, Dun, Dunk Pool, Ellery Sike, Five Yard, Forster's Hill, Four Fathom, Gastropod, Goat Island, Great, Greengate Well, Greenhead Bankhouses, Harelawhill, Hogg, Holmehead, Hope House, Jerrycalf, Jew, Jock's Pool, Junction, Kershopefoot, Kiln Pool, Kingbridge, Kingwater, Kinmont, Kitty Beck, Lamellibranch, Lanercost, Lawston,Leahill, Linns, Little, Lower Millerhill, Lower Oakwood, Low Tipalt, Lynecrook, M.A.1 to 14, Main Algal, Maggot's Pike, Maidenway, Martini, Merlin, Millerhill, Naworth, New House, Oakshaw, Oxford, Peel, Penton, Pink Pool, Piper's Cross, Plashett's Dun, Productus, *Pustula interrupta*, Rawney, Redesdale, Reeker, Rigghead, Rothbury, Rushy Knowe, Scar, Seminula, Shank Castle, Single Post, Spadeadam, Spy Hole, Stack Cleugh (Oolite) Suspension Bridge, *Syringothyris*, Three Yard, Tombstone, Tyne Bottom, Under, Upper Millerhill, Whickhope Linn, Whiteholme, Wiley Sike and Wood Park limestones
Linns Limestone, 158, 161–3, 290
Lion's Brae, 66
Lishaw Burn, 2, 103, 152, 240, 257
—— Linn, 257
—— Rigg, 103
List of fossils, 191–9
—— —— six-inch maps, xi
Lithology, igneous rocks, 242–50; limestones, 106, 156, 177–91; sandstones, 82, 106, 208–21, 230; strata, 5, 15, 25, 43, 66, 82, 106, 156, 226, 230
Lithostrotian junceum, 106, 116, 160–1, 167, 175, 197
—— *martini*, 92, 105, 113, 115–16, 120, 122, 124, 167, 171, 195
—— *pauciradiale*, 122, 195
—— *portlocki*, 115, 120, 167, 171, 195
Little Cranecleugh Burn, 150
—— Dove Crag, 110
—— Hare Grain, 65
—— Limestone, 223
—— Marven's Cleugh, 103, 214
—— Samuel's Crags, 139
—— Whickhope Burn, 2, 110, 144–6, 148, 151, 204, 265, 291
—— —— Coal, 148, 265
Localities, fossil, 199–205
Long Bar, 93–4, 267
—— Cleugh, 113–14, 202
Longcleugh Sike, 202
Long Crag, 93
—— Linn, 101
—— Rigg, 103, 255
Lonsdaleia floriformis, 167, 175, 198
Loup Sike, 161
Low Cranecleugh, 149
—— —— Coal, 149
Lowe Bush, 134
Lower *Antiquatonia* Band, 10, 66–7, 70–7, 169, 272, 283, 314, 321
—— Border Group, 15–81; classification, 10; conditions of deposition, 4, 11; correlation, 9–10; definition, 9; fossils, 16, 166–99; general sections, 19, 27, 44, 67; limestones, 15, 177, lithology, 4, 15; palaeogeography, 11; palaeontology, 16, 166–99; petrography, 4, 15, 208–13; sandstones, 208–13; thickness, 15; zonal position, 16, 166
—— Carboniferous, 15–221, classification, 10; contemporaneous downwarping, 12, 108, 232; correlation, 8–11; palaeontology, 166–207; sandstone petrography, 208–21, thickness, 4; volcanic activity, 242–5; zonal divisions, 8–11, 16, 156, 167–75
—— Clock's Cleugh, 139, 265
—— Coal Group, 10
—— —— Measures, 4, 6, 10, 13
—— *Dictyoclostus teres* Band, 17

Lower Freestones, 8, 10
—— Irthing Catchment, 2, 80, 100, 106, 125–31, 160, 164, 256
—— Lias, 6
—— Liddesdale Group, 5, 157; *see* Liddesdale Group
—— Limestone Group, 8–10, 156; *see* Liddesdale Group
—— Lynebank Beds, 17–18; *see* Lynebank Beds
—— Magnesian Limestone, 229
—— Millerhill Limestone, 106, 126–9, 139, 300
—— Netherhill Coal, 119, 121, 264, 296
—— Oakwood Limestone, 222
—— Tuedian Series, 15
—— Worm Bed, 180
Lowest algal horizon, 22, 180
—— recorded coal, 40
Low Floweryhirst, 73
—— Grains Farm, 42, 200
—— Park Fault, 79, 233, 239, 277
Lowshall, 267
Low Tipalt Limestone, 10–11, 156–61, 164, 324
Luckens, 115
—— Fault, 233, 238
LUMSDEN, G. I., 6, 157
—— and WILSON, R. B., 156, 171, 175, 222
Lynebank Beds, 17–25; classification, 10; comparative sections, 21; definition, 17; details, 20–5; distribution, 18; fossils, 168, 191; generalized section, 19; limestones, 18, 179; lithology, 4, 18; palaeontology, 168; sandstones, 211; thickness, 15, 18; volcanic activity, 18, 243; zonal position, 168
Lyne Catchment, 2, 70, 89, 115–19, 160, 253–4; *see also* Black Lyne and White Lyne catchments
Lynecrook, 307
—— Limestone, 122, 308
Lynedale Fault, 160, 233, 237
Lyneholmford Fault, 233, 238
Lyne River, 2, 9, 18, 105, 109, 115, 160, 203–4, 230–1, 237, 261, 302–5
Lynestead, 254

M.A.1 to M.A.14, 43–4
Maggot's Pike, 133
—— —— Limestone, 133
Maiden Way, 3
Maidenway Limestone, 67, 71–2, 77, 79, 189, 278–9, 320, 334
Main Algal Beds, 43–66; classification, 10; comparative sections, 45; definition, 43; details, 47–66; distribution, 46; fossils, 169, 192; generalized section, 44; limestones, 183; lithology, 4, 43; palaeontology, 169; sandstones, 213; thickness, 15
—— —— Reef, 185
—— —— Series, 15
—— Glaciation, 251
—— Reef, 17, 46, 52, 60–2, 187–8, 273
Malcolm's Still, 132, 136
Malls Burn, 122
Maps, list of six-inch, xi
March Sike, 114, 202
Marginal rudaceous sediment, 11
Marine transgression, 12
Marl Slate, 229
Martini Limestone, 84, 96
Marven's Cleugh, 103, 214
Melefarm Beck, 66, 77, 79, 213, 279
Mepsy's Crook, 252
Merlin Crags, 110, 316–17, 340
—— —— Coal, 265, 317
—— —— Sandstone, 219
—— Fault, 233, 316
—— Island Coal, 110, 265, 316
—— Limestone, 317
Mewsgate Fault, 233, 239
MEYER, H. O. A., 229
Michelinia Zone, 16, 78; *see* C_2 Zone
Micrite, 177–8
Middle Border Group, 82–104; classification, 10; comparative sections, 83; conditions of deposition, 4, 11; contemporaneous downwarping, 93; correlation, 9–10; definition, 9, 82; details, 84–104; fossils, 170, 194; limestones, 82; lithology, 4, 82, 208, 214; palaeogeography, 11; palaeontology, 170; petrography, 4, 82, 208, 214; sandstones, 82, 208, 214; thickness, 82; volcanic activity, 82, 88, 242; zonal position, 167
—— Coal Group, 10
—— —— Measures, 4, 10, 13
—— Crag, 93
—— —— Sandstone, 94
—— Limestone Group, 8–10; *see* Liddesdale Group
—— Permian Marls, 229
—— Sands, 251
—— Shield Beck, 99, 124-5
—— —— Bore, 83, 99, 170, 202, 268, 329
Mid Todholes, 254
Midgeholme Bore, 223

Mid-Northumberland, 8
Miller, H., Jnr., iii, 3, 8, 10, 108, 171
Millerhill Limestone, 106, 109, 328
Mills, D. A. C., iii, xi, 334, 338
Millstone Grit Series, 222–5; classification, 8–10; comparative sections, 223; conditions of deposition, 4, 11; correlation, 8–10, 222; definition, 11, 222; details, 224; distribution, 222; lithology, 4; palaeogeography, 11; thickness, 4, 222; zonal position, 222–3
Miospores, 172–4
'*Mitcheldeania*' *gregaria*, 69
Modiolus latus, 166
Mollin Wood, 77
Morris, L. S. O., 324
Moss Catherine, 302
—— —— Waterfall, 340
Mountain Limestones, 8
Muckle Hare Grain, 65, 75–6, 93, 201
—— Knowe, 104
—— Samuel's Crags, 139, 265
Muir-Wood, H. M., 166
Murrayholme, 200

Naiadites crassus, 109, 167, 170–1, 194, 196
Namurian, 9–12; *see* Millstone Grit Series
Naworth Bryozoa Band, 10–11, 105–6, 116, 156–8, 160, 326
—— Limestone, 10–11, 157–8, 160, 325–6
Nether Castle Cleugh, 87, 110–11
Netherhill, 264
Nether Hill Sike, 121
—— Oakshaw, 245
Neves, R., iii, 172
Newer drift, 251
New House, 38
—— —— Fault, 23, 38–9, 43, 233
—— —— Limestone, 26–7, 29, 32, 36, 38, 42, 182, 271, 288, 307
Nicholson, H. A., 69, 166
Nishaw Burn, 257, 263
Nixonstown, 20, 22, 200, 286
Nookfoot Sike, 159, 204
Nookgate Burn, 204
Norman castle, 3
North Christy's Crags, 136
—— —— ——, sandstone of, 137–8
Northern shoreline, 11
North Greenhill, 89, 253
—— Meadow Sandstone, 121, 215, 296
—— Northumberland, 8
Northumberland Trough, 5, 11–12
North Upper Denton Fault, 96, 124, 233, 239

Oakshaw Coal, 106, 119–20, 264, 296
—— —— Basin, 109, 120, 136, 237
—— Colliery, 120
—— Ford, 105, 107, 120, 203, 264
—— —— Quarry, 120, 203, 340
—— Limestone, 83, 107, 119–20, 124, 296, 311, 340
—— Sandstone, 82–4, 92, 215, 296
—— Syncline, 233, 237
—— Tuff, 107, 119–21, 242, 244–5, 340
Oakstock, 42
Oakwood coals, 222, 265
Oolite Sandwich, 27
Oolites, 178–9
Ooliths, 178
Orbiculoidea Shale, 44–6, 52, 59–63, 273, 281, 284, 314, 322
Osagia, 16
Ostracods, 166, 169–70, 172, 330
Otterstonelee Burn, 152
Ottonosia, 16
Ovatia bioni, 167, 169–70, 192–4
Overflow channels, 252–7
Owlhirst, 253
Ox Crags, 137
Oxford Limestone, 8–10

Padda Burn, 133–5, 265
Paddaburn Crags, 134, 340
—— Moor, 110
Palaeogeography, 11
Palaeontology, 16, 25, 166–207, 227–8
Pallyards Fault, 109, 233
Parkfoot Sike, 93, 124, 203
Parkgate Bridge, 278
Parkhead Sandstone, 27, 29, 32, 38, 212, 271, 293
Parkhouse Fault, 89, 233, 235–6, 240
Parkside Sike, 56, 254
Pattenside, 254
Peach, B. N., and Horne, J., 3, 156, 222, 226
Peat, 3, 6, 262–7; terraces, 263
Peel Fell, 341
—— Limestone, 27, 29, 41–3, 183, 270, 275, 307, 316
—— o' Hill, 38, 268
Pellets, algal, 178
Pennine Fault-system, 39
Penrith Sandstone, 229

Penton Anticline, 161–2, 236–7, 340
—— Bridge, 161–2, 219, 289
—— coals, 162, 222–4, 265
—— Colliery, 223–4
—— House, 225
—— Limestone, 156, 158, 161–3, 291
—— —— Group, 157
—— Linns, 156–8, 163, 197, 205, 222, 340
—— —— Fault, 162, 224, 233, 236–7
—— Mill, 224, 265
Permian, 4; *see* Permo-Triassic rocks
—— Basal Conglomerate, 230
Permo-Triassic rocks, 4, 6, 229–31
Peter's Crook, 162–3
—— —— Anticline, 236
Petrography; igneous rocks, 242–50; limestones, 106, 156, 177–91; sandstones, 82, 106, 208–21, 230; of strata, 5, 15, 25, 43, 66, 82, 106, 156, 226, 230
Photographs, list of, 339
Pike Burn, 133
Pikeburn Crags, 135–6
—— Fault, 233
Pike Plantation, 253
Pink Pool, 115
—— —— Limestone, 115, 122, 304–5
Piper Burn, 46
Piper's Cross Limestone, 157
Pitys primaeva, 84, 95–8, 170, 172, 329
Plantation Sike, 39–41
—— —— Sandstone, 27, 29, 34, 38–43, 48, 212, 270, 285, 307, 316
Plants, 168, 170, 227
Plashetts Coal, 107–8, 136, 149, 151, 265
Plashetts Dun Limestone, 157
Pleistocene, 3, 251–7
Pollen zones, 262–3
Poppingstone Sandstone, 126, 300
Posidonia becheri, 167, 175, 199
Pre-glacial river courses, 6, 258
PRICE, R. H., iii, xi, 222, 329, 331
Primary watershed, 1, 258
Priorlancy Bore, 71, 77–8, 201, 268, 331
Productus garwoodi, 167, 196
Productus Limestone, 84, 96
Pudding Crook, 113–14, 202, 246
Punctospirifer scabricosta, 167, 169–70, 193–4
Pustula interrupta, 16–18, 22, 166–8, 191
—— —— Limestone, 180
—— *pyxidiformis*, 167–9, 193

Quarries, 23, 38, 60, 63, 66, 68, 77, 88, 90, 93, 95, 114, 117, 125, 151, 159, 163, 218, 246, 253, 255, 266–7, 340; *see also* Banks, Leagair, Oakshaw Ford, Station, Steel's and Stockastead quarries
Quarry Sandstone, 67, 77, 79, 279, 320, 332
Quartz-dolerite, 242, 244, 246

Rack Bridge Sandstone, 116
Rae Burn, 2, 117–18, 253–4, 264
Raeholes Sike, 100
RAMSBOTTOM, W. H. C., iii
Raven's Nest Crag, 148
Raw, 256
Rawney, 23, 200, 243, 276
—— Limestone, 18, 21, 23–4, 181, 276, 286
—— Tuff, 18–19, 21, 23, 242–3
Recent deposits, 3, 258–63
Red beds, 13, 226, 230–1
Reddened strata, 6, 13, 226
Redesdale–Dun miscorrelation, 9
—— Ironstone Shale, 8, 157
—— Limestone, 8–10, 157
Red Sike, 262
—— Skirts, 93
Reef-like limestone, 164
Reefs, algal, 16
Reeker Coal, 265, 291
—— Limestone, 136, 291
—— Pike, 136, 144
—— —— Fault, 240
—— Sike, 204, 291
Retreat of ice, 6, 251–7
Rhynchonellid Sandstone, 161–2, 290
Rhythmic sedimentation, 6, 11, 15, 25, 66, 107, 156
RICHEY, J. E., *see* Barrett and Richey
Riddings, 261, 266
—— Bore, 230
Riding Grain, 17, 84, 86–7, 110, 202, 235
Rigghead Limestone, 26–7, 29, 31, 34, 36–43, 48, 183, 270, 285, 307, 316
River development, 258–61
—— terraces, 3, 261–2, 341
Rivers, 2, 261–2
Roadhead, 120–1
—— Drift, 121
Road metal, 267
Roansgreen, 268
Roanstrees, 254
Robbie's Grain, 28, 56–7, 238
Robin Hood's Well, 77
Robin's Knowe, 145
ROBINSON, J. E., iii, 9, 157, 166, 168–70, 330

Rob's Sike, 80
Robson, D. A., 11, 208
Roman fort, 3, 266
Rooms Crag Cottage, 93
Rothbury, 46
—— Limestones, 8–10
Rotten Grain, 100
Rough Grain, 75–6, 93, 201–2, 233, 248
—— —— Fault, 76, 233, 240
—— Pike, 104
—— Sike, 24, 256
Round Crag, 93
Routledge Burn, 2, 20, 31, 199, 235, 246
—— —— Anticline, 31, 33–4, 48, 233, 235, 237, 285
Rowanburnhead Bore, 223
Rowantree Sike, 111
Rugosochonetes cumbriensis, 80, 167, 170, 194, 339
Rushy Crag, 93
—— Knowe Limestone, 138
Rutty Pool, 114
Rye Knowe, 255

Saccamminopsis fusilinaformis, 175
St. Bees Sandstone, 4, 6, 229–30, 267
—— —— Shale, 4, 6, 229–30
St. Cuthbert's Church 267; cross at, 3, 94, 267
—— —— Hall, 50
Sand and gravel, 6, 252–6, 267
Sandstones, Lower Carboniferous, 82, 107, 208–21; chloritic, 103, 209, 214; for building and road metal, 94, 266–7; irregularly contorted bedding, 74, 82, 107, 110; metamorphosed, 103, 248; provenance, 12, 211; *see also* Ashfell, Barron's Pike, Bridge, Bull Crag, Bullrigg, Christy's Crags, Collering, Crammel Linn, Crying Crags, Dumblar Rigg, Earthwork, Fell, Green Goose, Grey's Crags, Hennel Cleugh, High Grains, Lampert, Merlin Crags, Middle Crag, North Christy's Crags, North Meadow, Oakshaw, Parkhead, Plantation Sike, Poppingstone, Quarry, Park Bridge, Rhynchonellid, Seven Linns, Shank Wood, Spy Rigg, Tinkler Crag, Tod Crag, Waterfall, Whita and Woodhead Crag sandstones.
——, Permo-Triassic, 229–31
'Sandwich', 26, 37, 39–41, 270
Sandy Sike, 254, 256
Saughy Fault, 146, 233
—— Sike, 146, 148
Scald Sike, 150
Scaleby Moss, 263
Scar Limestone, 158
Schuchertella ambigua, 17, 68, 166–70, 191, 193–4, 339
Scott Beds, 113, 171
Scottish ice, 251
—— Midland Valley trough, links with, 11
Scremerston Coal Group, 8–10, 105–6, 108; *see* Upper Border Group
Sections (graphic): Liddesdale Group, 158; Lower Border Group, general 19, 27, 44, 67; comparative, 21, 29, 41, 45, 71; Middle Border Group, 83; Millstone Grit, 223; Upper Border Group, Plate V
Sedimentary rhythms, 6, 15, 25, 66, 107, 156
Selbystown, 306
Seminula Limestone, 319
Semiplanus sp. nov. 113, 120, 167, 171, 190, 196
Serpula cf. *advena* Band, 43
Serpulids, 17, 177
Seven Linns, 139, 265, 339
—— —— Coal, 135, 138–9, 264–5
—— —— Sandstone, 136, 139, 148, 280, 339
Shaly Sike, 140
Shank Castle, 109
—— —— Limestone, 116–17, 303
—— End, 109, 264
—— Wood Sandstone, 109, 115, 117–18, 303
Shawstown, 253
—— Burn, 118
Shiel Knowe, 255
Shield Sike, 131
Shilburnhaugh, 151
—— Coal, 107–8, 136, 148, 151–2, 265
Shopford, *see* Bewcastle
—— Fault, 39, 233, 239
Short Cleugh (Lewis Burn Catchment), 104, 152, 247–8
—— —— (Whickhope Burn Catchment), 149
Shortshank Sike, 28
Show Burn, 2, 59, 73, 93, 188–9, 201, 256
—— —— Fault, 74
Side, 63
Sighty Crag, 109, 124, 136

Sighty Crags, 136, 139, 154
Single Post Limestone, 158
Skelton Pike, 70, 237
Slacks, 255
Slaty Crag, 93
—— Grain, 153
—— Pike, 133
Sleet Beck, 2, 90, 119, 202, 254
SMITH, D. B., 229
SMITH, S., 3, 8, 157
Smithy Gill, 54
Smooring Sike, 240
Sockles Stell, 75
Solport, 109
—— Coal, 118
—— Mill, 118
Solway Basin, 229
South Tyne, River, 259–60
Southern Uplands Massif, 5, 11, 232
Southward Ford, 109, 117, 253
Spadeadam area, 6, 82, 109
—— Beds, 77–8, 94
—— Bores: No. 1 (Middle Shield), 83, 99, 170, 202, 268, 329; No. 2 (Priorlancy), 71, 77–8, 201, 268, 331; No. 3 (Camp), 105, 124, 172, 268, 334; No. 4 (Greymare Hill), 100, 215, 268, 338
—— Farm, 94, 189
—— Forest, *see* Spadeadam Waste
—— Limestone, 93–4, 319
—— Research Establishment, 268
—— Waste, 6, 239, 256 263, 268
Sphalerite, 141
Spirorbis limestone, 226
Springs, 263, 268
Spy Crags, 131
—— Hole Limestone, 128–9, 135, 300, 340
—— Pit, 264
—— Rigg, 106, 109, 340
—— —— Fault, 128, 233, 239, 340
—— —— Sandstone, 126–8, 131, 139, 217, 299, 302, 308, 328, 340
Stack Cleugh, 40–1, 45, 61, 183, 315
—— —— Oolite, 27, 29, 40–3, 183, 270, 316
Stantling Burn, 101
Stanwix Shales, 229
Stapleton, 47, 253, 267
—— Anticline, 25, 35, 47, 70, 109, 233, 237–8
Station Quarry, 68, 201
Steel's Quarry, 151–2
Stenoscisma isorhyncha, 167, 171, 190, 196
Steppings, 24
Stockastead Quarry, 37, 272
Stone Beck, 83, 95, 202, 216
Stonegarthside, 252
—— Dyke, 246
—— Hall, 203
Stoneknowe, 254
Stony Sike, 103, 152
Storey's Sike, 89
Stot Sike, 153
Stower Hill, 150
Streams, 2
Striae, 251, 257
Stripe Rigg, 134
Structural analysis, 235
—— trend, 234–5
Structure, 232–41
Sub-boreal Zone, 262
Sunday Burn, 126, 301
Sundayburn Linn, 126–7, 301–2, 340
Sunnythwaite, 117, 253
Suspension Bridge Limestone, 122, 303–4
Swallow Crags, 134
Swallowholes Sike, 160
Symbiotic association, 177
Syringothyris-Derbyia Band, 72–3
—— *exoleta*, 17, 68, 166–7, 170, 193–4
—— Limestone, 17, 67–8, 71–5, 78–9, 169, 189, 278–9, 313, 320, 331, 339

Tarn Beck, 2, 100, 133
—— —— Syncline, 233
TATE, G., 8, 10
TAYLOR, B. J., iii
TEALL, J. J. H., 246
Terraces, 6, 261–3
Tertiary dykes, 4–6, 249–50
—— earth movements, 6, 232
The Beacon, 77
—— Beck, 2, 17, 58, 72, 201
—— Butt, 77
—— Flatt, 255
—— Flosh, 253
—— Gill, 255–6
—— Knares, 135, 137
—— Linns, 64
—— Pot, 159, 265
—— Rigg, 142, 257
Thicknesses of strata, 5, 15, 82, 108, 156, 222, 226, 229
Thief Cleugh, 113, 202, 245
Thirlwall, 131
—— Coal, 106, 130–1, 264, 327
—— Colliery, 130–1, 264
—— Common, 263, 268

Thirlwall No. 1 Bore, 160
Tholeiite, 242, 249
Thornyland, 253
Three Yard Limestone, 158
Throssburn Foot, 126, 129
—— —— Coal, 129, 264, 300
Tinkler Crag Sandstone, 124–5, 335
Tipalt Burn, 2–3, 160–1, 205, 220, 250, 259–60
—— Catchment, 131, 160, 163
Tod Crag, 70, 93, 101
—— —— Sandstone, 93
Toddle Burn, 161
Todholes, 123
—— Fault, 233, 237
Tombstone Limestone, 158, 161–2, 290
Tom's Crags, 101
Tornquistia polita, 167, 175, 198
Tother Hill, 253, 267
Tournaisian, 10, 16, 167
Trias, *see* Permo-Triassic rocks
TROTTER, F. M. (and HOLLINGWORTH, S. E.), iii, xi, 3, 8, 10, 84, 96, 105, 156–7, 208, 226, 229, 251–2, 261, 324
Trout Beck, 84, 96–8, 124, 202
Tuedian, 8–10
Tuff, 18–19, 21, 23, 84, 107, 119–21, 242–5, 340
Tweed, River, 8
Tweeden Burn, 46
Twolads Crag, 93
Tyne Bottom Limestone, 158
—— Gap, 259–61
Tyne, River, 258

Under Limestone, 158
Upper *Antiquatonia* Band, 67–8, 71–3, 75, 77–9, 188–9, 278, 283, 313, 320
—— Bernician, 9
—— Border Group, 105–55; classification 10; comparative sections, Plate V; conditions of deposition, 4, 11; contemporaneous downwarping, 12, 108, 232; correlation, 10, 105; definition, 9, 105; details, 110–55; distribution, 108; fossils, 171, 195–7; limestones, 106; lithology, 4, 106–7; palaeogeography, 11; palaeontology, 171; petrography, 4, 106–7, 208–11, 215–19; sandstones, 107, 208–11, 215–19: thickness, 108; volcanic activity, 107, 119–21, 245; zonal position, 167
—— Carboniferous, 4–6, 8, 10–13, 222–8
—— Clock's Cleugh, 139
—— Coal Group, 10
Upper Coal Measures, 4, 10, 13, 226–8
—— '*Dictyoclostus*' *teres* Band, 43, 66
—— Irthing Catchment, 2, 80, 100–2, 131–5, 256
—— Liddesdale Group, 5, 157; *see* Liddesdale Group
—— Limestone Group, 8–10, 156, 222; *see* Millstone Grit Series
—— Lynebank Beds, 18
—— Magnesian Limestone, 229
—— Millerhill Limestone, 106, 125, 128–9, 139, 300
—— Nether Castle Cleugh, 87, 110
—— Netherhill Coal, 119, 121, 264, 296
—— Permian Marls, 229
—— Worm Bed, 180

Vale of Eden, 12
Vent agglomerate, 123, 245
Viséan, 10, 166–8
Volcanic rocks, 6, 17–19, 21, 23, 82–4, 88, 107, 119–21, 123, 242–5

Wakey Hill, 91
Wallshield, 131
—— Colliery, 130, 264
Walton Moss, 268
WARD, J. C., iii, 3
Wark Burn, 259
Water supply, 268
Waterfall Sandstone, 27, 38, 41, 42, 270, 316
Waterhead Common, 263, 268
—— Fault, 233, 239
Watleyhirst, 225
—— Fault, 162–3, 233, 236
Watt's Sike, 70
Waverley Coal, 118, 264
Weasel Crags, 134
Wedder Lairs, 142, 263
Wellington Gate, 20, 255
WESTOLL, T. S. and others, 238
Westphalian, 10
Wham's Sike, 75, 201
Whaup Crags, 134
Whickhope, 151
—— Burn, 2, 110, 149–52, 204, 218–19, 240, 265, 316, 340
—— —— Catchment, 2, 102, 139–52, 257
—— Coal, 265, 317
—— Linn, 265
—— —— Fault, 146, 233
—— —— Limestone, 107, 136, 138, 146
—— Nick, 341

Whickhope Nick Fault, 240
Whickhopenick Sike Coal, 137, 265, 291
Whin Sill, 242, 245
Whintingstown, 120
Whita Sandstone, 15
Whitberry Band, 9–10, 15, 66–7, 71, 73–4, 76, 80, 82–3, 92–4, 170, 312, 319, 339
—— Burn, 2, 60, 68, 71–2, 83, 92, 189, 201–2, 213-14, 319, 339
White Beck, 2, 41, 42, 45–6, 62, 74, 201, 212–13, 321
Whitehill, 139
—— Moor, 135, 264
Whiteholme Limestone, 119, 122, 298
Whiteknowe, 252
White Lyne, 18, 20–2, 24–5, 29, 36, 45–6, 59, 65, 68, 71, 73, 75, 82–3, 91, 109, 124, 180, 188–9, 200–3, 211, 238, 258, 286, 306–7, 310, 339
—— —— Catchment, 2, 20–5, 35–43, 59–66, 72–7, 91–4, 124, 255–6
—— Preston, 63, 74, 239
—— —— Fault, 63
—— Rigg, 77
Whiterigg Serpula Band, 67, 71, 77, 78, 189, 278, 320, 333
White Sike, 146
Wiley Sike Bore, 126, 268
—— —— Limestone, 126, 299, 328
Williams, J. E., 172
Wilson, R. B., 11, 197; *see also* Lumsden and Wilson
Windy Crags, 142
Windyhill, 253
Wintershields, 60
Wood Park Limestone, 175
Woodhead Crag Sandstone, 44–6, 61, 63, 66, 213, 273, 322
Workings: *see* Coal seams
'Worm' bed, 60
Wythes Fault, 84, 86–7, 110, 233, 235

Yearning Sike, 254
Yeat Sike, 25, 36
Yellowmire Sike, 264
Yett Burn, 2, 94, 103, 109–10, 141, 152–4, 204, 214
Yoredale type, cyclic deposits of, 11

Zones, Carboniferous, 8–11, 16, 156, 166–9, 175, 222–3, 227
Z_2 Zone, 16

UNIVERSITY
5 OCT 1970

Dd 147220 K.12

DURHAM UNIVERSITY
SCIENCE SECTION LIBRARY
- 5 OCT 1970

3 0104 00310769 9

UNIVERSITY LIBRARY
DURHAM

CLASS No. 55(410) G.G.E.12
AUTHOR DAY
ACCESSION No. S51916

3 DEC 1970
19 JAN 1971
- 4 MAR 1971
23 JAN 1973
31 MAY 1974
31 MAY 1974
31 MAY 1975
- 2 DEC 1975
31 MAY 1980

1 NOV 1980
- 7 JUN 1983
28 OCT 1986
24 FEB 1987
23 JAN 1990
- 8 DEC 1992
29 MAY 2001
30 OCT 2001
28 MAY 2002

72

A4587

BEWCASTLE

12

554.2
6718406